US009163174B2

(12) United States Patent
Alleyne et al.

(10) **Patent No.:** **US 9,163,174 B2**

(45) **Date of Patent:** **Oct. 20, 2015**

(54) **HIGHLY EFFICIENT PHOSPHORESCENT MATERIALS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 951 days.

(21) Appl. No.: **13/345,285**

(22) Filed: **Jan. 6, 2012**

(65) **Prior Publication Data**

US 2013/0169148 A1 Jul. 4, 2013

Related U.S. Application Data

(60) Provisional application No. 61/583,045, filed on Jan. 4, 2012.

(51) **Int. Cl.**

H01L 51/54	(2006.01)
C09K 11/06	(2006.01)
H01L 51/00	(2006.01)
C07F 15/00	(2006.01)
H05B 33/10	(2006.01)
H01L 51/50	(2006.01)

(52) **U.S. Cl.**

CPC ***C09K 11/06*** (2013.01); ***C07F 15/0033*** (2013.01); ***H01L 51/0085*** (2013.01); ***H05B 33/10*** (2013.01); *C09K 2211/1007* (2013.01); *C09K 2211/1011* (2013.01); *C09K 2211/1029* (2013.01); *C09K 2211/185* (2013.01); *H01L 51/5016* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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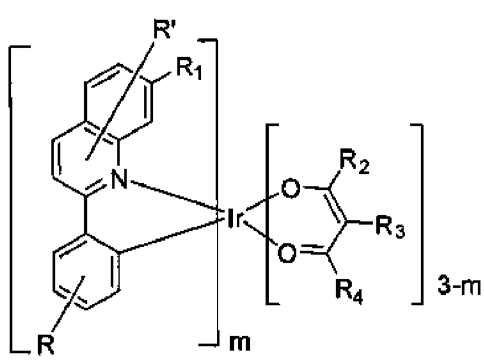
(57) **ABSTRACT**

Novel phosphorescent heteroleptic iridium complexes with substituted phenylquinoline ligands are provided. The alkyl substitution on the phenylquinoline ligands together with larger alkyl substituents on the acetylacetone-derived ligands produces complexes with improved properties that are useful when incorporated into OLED devices.

16 Claims, 3 Drawing Sheets



Formula I

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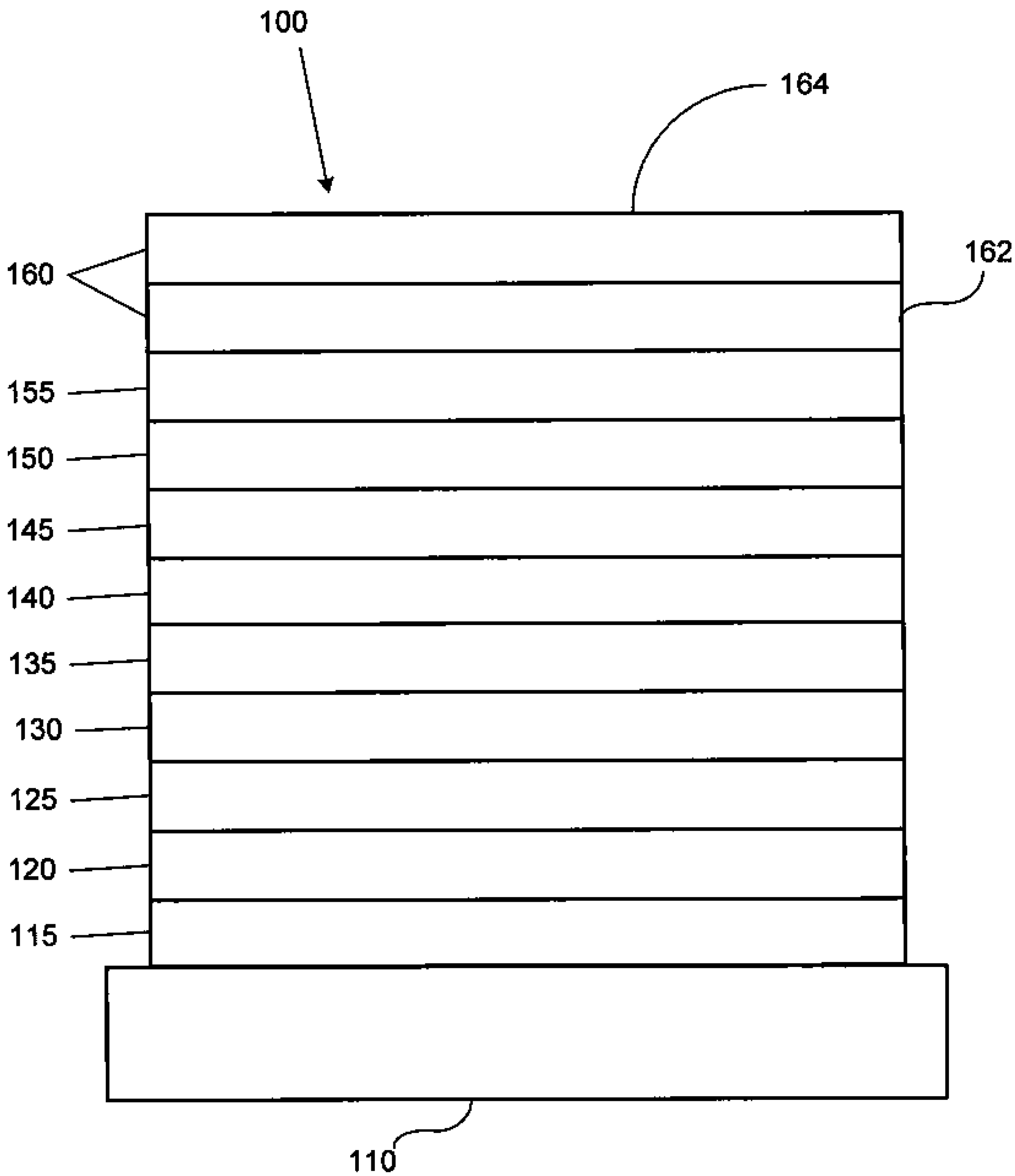


FIGURE 1

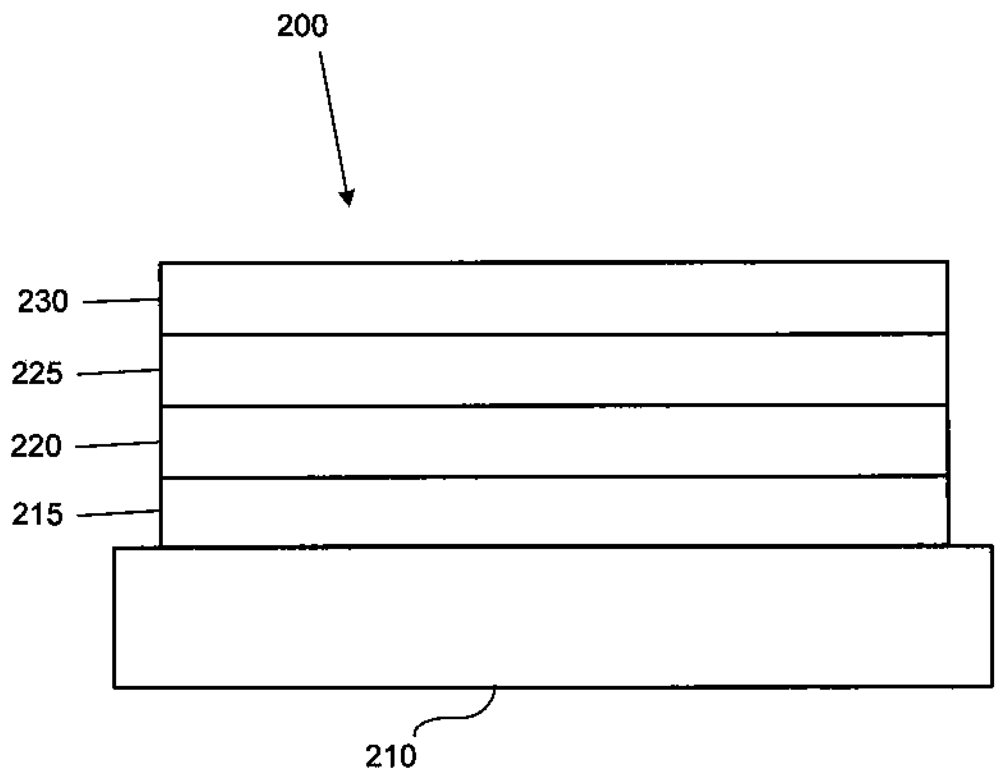
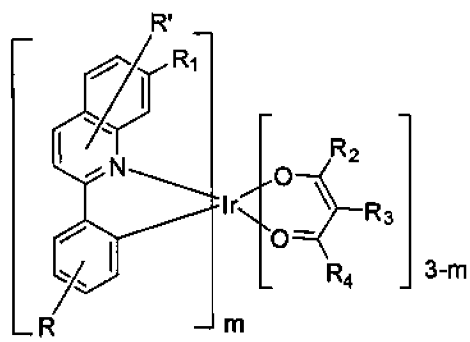


FIGURE 2



Formula I

FIGURE 3

HIGHLY EFFICIENT PHOSPHORESCENT MATERIALS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Application No. 61/583,045, filed Jan. 4, 2012, the disclosure of which is herein expressly incorporated by reference in its entirety.

The claimed invention was made by, on behalf of, and/or in connection with one or more of the following parties to a joint university corporation research agreement: Regents of the University of Michigan, Princeton University, The University of Southern California, and the Universal Display Corporation. The agreement was in effect on and before the date the claimed invention was made, and the claimed invention was made as a result of activities undertaken within the scope of the agreement.

FIELD OF THE INVENTION

The present invention relates to 2-phenylquinline complexes of iridium, and in particular to 2-phenylquinolines containing an alkyl substituent having at least four carbon atoms. These iridium complexes are useful materials in OLED devices.

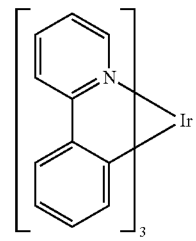
BACKGROUND

Opto-electronic devices that make use of organic materials are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic opto-electronic devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. Examples of organic opto-electronic devices include organic light emitting devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. For OLEDs, the organic materials may have performance advantages over conventional materials. For example, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants.

OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly interesting technology for use in applications such as flat panel displays, illumination, and backlighting. Several OLED materials and configurations are described in U.S. Pat. Nos. 5,844,363, 6,303,238, and 5,707,745, which are incorporated herein by reference in their entirety.

One application for phosphorescent emissive molecules is a full color display. Industry standards for such a display call for pixels adapted to emit particular colors, referred to as "saturated" colors. In particular, these standards call for saturated red, green, and blue pixels. Color may be measured using CIE coordinates, which are well known to the art.

One example of a green emissive molecule is tris(2-phenylpyridine) iridium, denoted $Ir(ppy)_3$, which has the following structure:



In this, and later figures herein, we depict the dative bond from nitrogen to metal (here, Ir) as a straight line.

As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials that may be used to fabricate organic opto-electronic devices. "Small molecule" refers to any organic material that is not a polymer, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances. For example, using a long chain alkyl group as a substituent does not remove a molecule from the "small molecule" class. Small molecules may also be incorporated into polymers, for example as a pendent group on a polymer backbone or as a part of the backbone. Small molecules may also serve as the core moiety of a dendrimer, which consists of a series of chemical shells built on the core moiety. The core moiety of a dendrimer may be a fluorescent or phosphorescent small molecule emitter. A dendrimer may be a "small molecule," and it is believed that all dendrimers currently used in the field of OLEDs are small molecules.

As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. Where a first layer is described as "disposed over" a second layer, the first layer is disposed further away from substrate. There may be other layers between the first and second layer, unless it is specified that the first layer is "in contact with" the second layer. For example, a cathode may be described as "disposed over" an anode, even though there are various organic layers in between.

As used herein, "solution processible" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

A ligand may be referred to as "photoactive" when it is believed that the ligand directly contributes to the photoactive properties of an emissive material. A ligand may be referred to as "ancillary" when it is believed that the ligand does not contribute to the photoactive properties of an emissive material, although an ancillary ligand may alter the properties of a photoactive ligand.

As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram, with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A "higher" HOMO or LUMO energy level appears closer to the top of such a diagram than a "lower" HOMO or LUMO energy level.

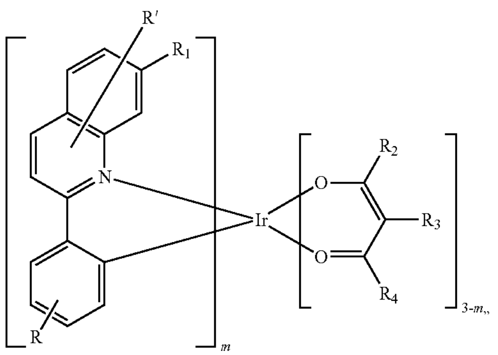
As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum level, this means that a "higher" work function is more negative. On a conventional energy level diagram, with the vacuum level at the top, a "higher" work function is illustrated as further away from the vacuum level in the downward direction. Thus, the definitions of HOMO and LUMO energy levels follow a different convention than work functions.

More details on OLEDs, and the definitions described above, can be found in U.S. Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

In one aspect, a compound having the formula:

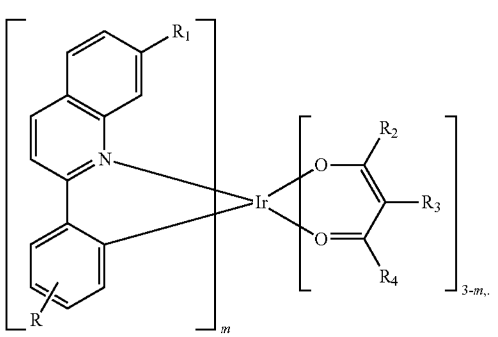
Formula I



is provided. In the compound of Formula I, R_1 is selected from the group consisting of alkyl, cycloalkyl, heteroalkyl, aryl, heteroaryl, and combinations thereof, wherein R_1 has four or more carbon atoms. R, R', R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of the R_2, R_3 and R_4 has two or more carbon atoms, and R and R' may represent mono, di, tri, tetra substitution, or no substitution. Two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring, and m is 1 or 2.

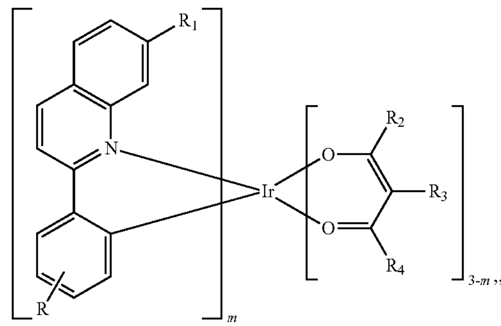
In one aspect, the compound has the formula:

Formula II



In one aspect, the compound has the formula:

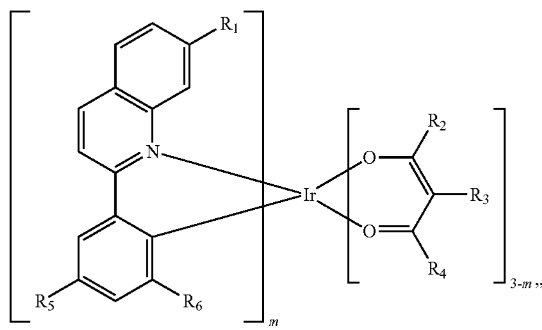
Formula II



wherein R_1 is selected from the group consisting of alkyl, cycloalkyl, and combinations thereof. In one aspect, m is 2.

In one aspect, the compound has the formula:

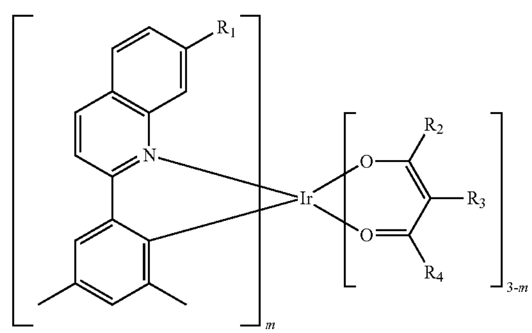
Formula III



wherein R_5 and R_6 are alkyl.

In one aspect, the compound has the formula:

Formula IV



In one aspect, R_2, R_3, and R_4 are independently selected from the group consisting of aryl, alkyl, hydrogen, deuterium, and combinations thereof. In another aspect, R_2, R_3, and R_4 are independently selected from the group consisting of methyl, $CH(CH_3)_2$, $CH_2CH(CH_3)_2$, phenyl, cyclohexyl, and combinations thereof.

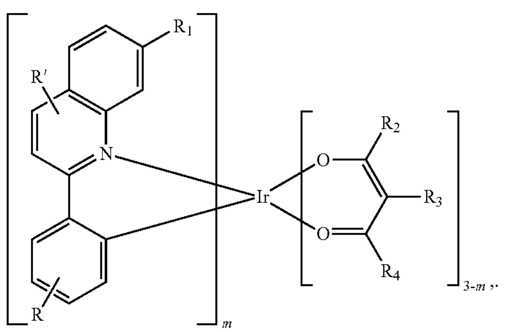
In one aspect, R_1 is alkyl. In one aspect, R_1 is selected from the group consisting of: $CH_2CH(CH_3)_2$, cyclopentyl, $CH_2C(CH_3)_3$, and cyclohexyl. In one aspect, R_1 is $CH_2CH(CH_3)_2$.

In one aspect, R_3 is hydrogen or deuterium and R_2 and R_4 are independently selected from $CH(CH_3)_2$ and $CH_2CH(CH_3)_2$.

In one aspect, the compound is selected from the group consisting of Compound 1-Compound 33.

In one aspect, a first device is provided. The first device comprises a first organic light emitting device, further comprising an anode, a cathode and an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

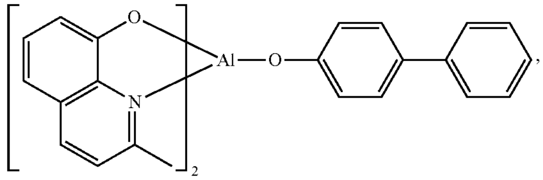
Formula I

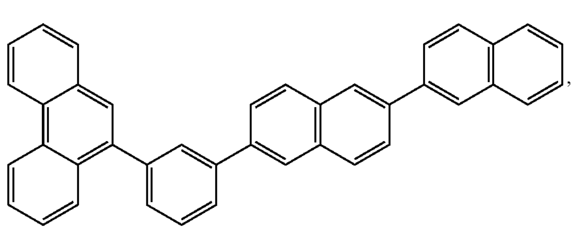


In the compound of Formula I, R_1 is selected from the group consisting of alkyl, cycloalkyl, heteroalkyl, aryl, heteroaryl, and combinations thereof, wherein R_1 has four or more carbon atoms. R, R', R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfonyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of the R_2, R_3 and R_4 has two or more carbon atoms, and R and R' may represent mono, di, tri, tetra substitution, or no substitution. Two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring, and m is 1 or 2.

In one aspect, the first device is a consumer product. In one aspect, the first device is an organic light-emitting device. In one aspect, the first device comprises a lighting panel.

In one aspect, the organic layer further comprises a host. In one aspect, the host comprises a metal 8-hydroxyquinolate. In one aspect, the host is selected from the group consisting of:





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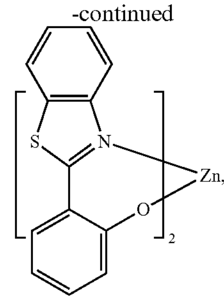
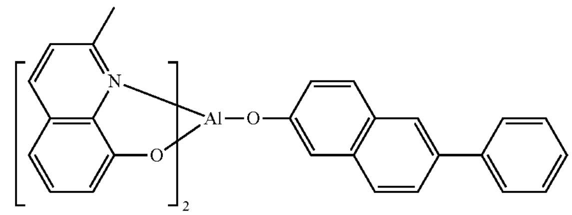




and combinations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an organic light emitting device.

FIG. **2** shows an inverted organic light emitting device that does not have a separate electron transport layer.

FIG. **3** shows a compound of Formula I.

DETAILED DESCRIPTION

Generally, an OLED comprises at least one organic layer disposed between and electrically connected to an anode and a cathode. When a current is applied, the anode injects holes and the cathode injects electrons into the organic layer(s). The injected holes and electrons each migrate toward the oppositely charged electrode. When an electron and hole localize on the same molecule, an "exciton," which is a localized electron-hole pair having an excited energy state, is formed. Light is emitted when the exciton relaxes via a photoemissive mechanism. In some cases, the exciton may be localized on an excimer or an exciplex. Non-radiative mechanisms, such as thermal relaxation, may also occur, but are generally considered undesirable.

The initial OLEDs used emissive molecules that emitted light from their singlet states ("fluorescence") as disclosed, for example, in U.S. Pat. No. 4,769,292, which is incorporated by reference in its entirety. Fluorescent emission generally occurs in a time frame of less than 10 nanoseconds.

More recently, OLEDs having emissive materials that emit light from triplet states ("phosphorescence") have been demonstrated. Baldo et al., "Highly Efficient Phosphorescent Emission from Organic Electraluminescent Devices," Nature, vol. 395, 151-154, 1998; ("Baldo-I") and Baldo et al., "Very high-efficiency green organic light-emitting devices based on electrophosphorescence," Appl. Phys. Lett., vol. 75, No. 3, 4-6 (1999) ("Baldo-II"), which are incorporated by reference in their entireties. Phosphorescence is described in more detail in U.S. Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

FIG. **1** shows an organic light emitting device **100**. The figures are not necessarily drawn to scale. Device **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, an electron blocking layer **130**, an emissive layer **135**, a hole blocking layer **140**, an electron transport layer **145**, an electron injection layer **150**, a protective layer **155**, and a cathode **160**. Cathode **160** is a compound cathode having a first conductive layer **162** and a second conductive layer **164**. Device **100** may be fabricated by depositing the layers described, in order. The properties and functions of these various layers, as well as example materials, are described in more detail in U.S. Pat. No. 7,279,704 at cols. 6-10, which are incorporated by reference.

More examples for each of these layers are available. For example, a flexible and transparent substrate-anode combination is disclosed in U.S. Pat. No. 5,844,363, which is incorporated by reference in its entirety. An example of a p-doped hole transport layer is m-MTDATA doped with F.sub.4-TCNQ at a molar ratio of 50:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. Examples of emissive and host materials are disclosed in U.S. Pat. No. 6,303,238 to Thompson et al., which is incorporated by reference in its entirety. An example of an n-doped electron transport layer is BPhen doped with Li at a molar ratio of 1:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, disclose examples of cathodes including compound cathodes having a thin layer of metal such as Mg:Ag with an overlying transparent, electrically-conductive, sputter-deposited ITO layer. The theory and use of blocking layers is described in more detail in U.S. Pat. No. 6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

FIG. **2** shows an inverted OLED **200**. The device includes a substrate **210**, a cathode **215**, an emissive layer **220**, a hole transport layer **225**, and an anode **230**. Device **200** may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device **200** has cathode **215** disposed under anode **230**, device **200** may be referred to as an "inverted" OLED. Materials similar to those described with respect to device **100** may be used in the corresponding layers of device **200**. FIG. **2** provides one example of how some layers may be omitted from the structure of device **100**.

The simple layered structure illustrated in FIGS. **1** and **2** is provided by way of non-limiting example, and it is understood that embodiments of the invention may be used in connection with a wide variety of other structures. The specific materials and structures described are exemplary in nature, and other materials and structures may be used. Functional OLEDs may be achieved by combining the various layers described in different ways, or layers may be omitted entirely, based on design, performance, and cost factors. Other layers not specifically described may also be included. Materials other than those specifically described may be used. Although many of the examples provided herein describe various layers as comprising a single material, it is understood that combinations of materials, such as a mixture of host and dopant, or more generally a mixture, may be used. Also, the layers may have various sublayers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device **200**, hole transport layer **225** transports holes and injects holes into emissive layer **220**, and may be described as a hole transport layer or a hole injection layer. In one embodiment, an OLED may be described as having an "organic layer" disposed between a cathode and an anode. This organic layer may comprise a single layer, or may further comprise multiple layers of different organic materials as described, for example, with respect to FIGS. **1** and **2**.

Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. Pat. No. 5,247,190 to Friend et al., which is incorporated by reference in its entirety. By way of further example, OLEDs having a single organic layer may be used. OLEDs may be stacked, for example as described in U.S. Pat. No. 5,707,745 to Forrest et al, which is incorporated by reference in its entirety. The OLED structure may deviate from the simple layered structure illustrated in FIGS. **1** and **2**. For example, the substrate may include an angled reflective surface to improve out-coupling, such as a mesa structure as described in U.S. Pat. No. 6,091,195 to Forrest et al., and/or a pit structure as described in U.S. Pat. No. 5,834,893 to Bulovic et al., which are incorporated by reference in their entireties.

Unless otherwise specified, any of the layers of the various embodiments may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat. Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. patent application Ser. No. 10/233,470, now U.S. Pat. No. 7,431,968, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution based processes. Solution based processes are preferably carried out in nitrogen or an inert atmosphere. For the other layers, preferred methods include thermal evaporation. Preferred patterning methods include deposition through a mask, cold welding such as described in U.S. Pat. Nos. 6,294,398 and 6,468,819, which are incorporated by reference in their entireties, and patterning associated with some of the deposition methods such as ink jet and OVA). Other methods may also be used. The materials to be deposited may be modified to make them compatible with a particular deposition method. For example, substituents such as alkyl and aryl groups, branched or unbranched, and preferably containing at least 3 carbons, may be used in small molecules to enhance their ability to undergo solution processing. Substituents having 20 carbons or more may be used, and 3-20 carbons is a preferred range. Materials with asymmetric structures may have better solution processibility than those having symmetric structures, because asymmetric materials may have a lower tendency to recrystallize. Dendrimer substituents may be used to enhance the ability of small molecules to undergo solution processing.

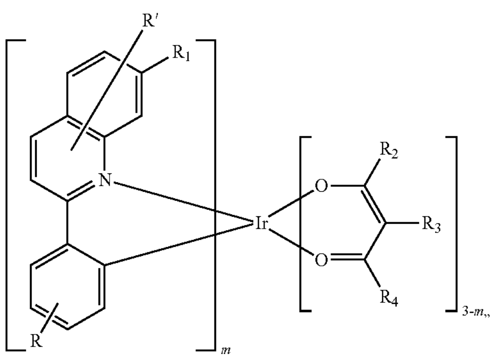
Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, medical monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent displays, flexible displays, laser printers, telephones, cell phones, personal digital assistants (PDAs), laptop computers, digital cameras, camcorders, viewfinders, micro-displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.).

The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

The terms halo, halogen, alkyl, cycloalkyl, alkenyl, alkynyl, arylkyl, heterocyclic group, aryl, aromatic group, and heteroaryl are known to the art, and are defined in U.S. Pat. No. 7,279,704 at cols. 31-32, which are incorporated herein by reference.

In one embodiment, a compound having the formula:

Formula I

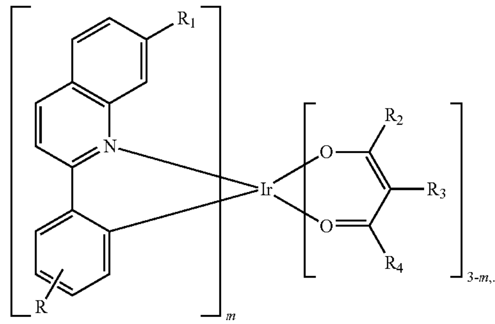


is provided. In the compound of Formula I, R_1 is selected from the group consisting of alkyl, cycloalkyl, heteroalkyl, aryl, heteroaryl, and combinations thereof, wherein R_1 has four or more carbon atoms. R, R', R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkenyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphine, and combinations thereof. At least one of the R_2, R_3 and R_4 has two or more carbon atoms, and R and R' may represent mono, di, tri, tetra substitution, or no substitution. Two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring, and m is 1 or 2.

As discussed below in the Device Example section, it has been unexpectedly discovered that when R_1 is an alkyl group containing four or more carbons and at least one of R_2-R_4 has two or more carbons, that the resulting iridium complexes can be used to created OLED devices with superior properties. Compounds of Formula I are superior to compounds that have only R_1 with four or more carbons or only at least one of R_2-R_4 has two or more carbons. The aforementioned substitution patter is believed to be synergistic. Without being bound by theory, the alkyl groups are believed to favorably affect the molecular packing in the crystal lattice of compounds of Formula I, such that when these compounds are used in OLED devices, the resulting devices have improved operational parameters such as increased luminance efficiency and narrow emission spectra.

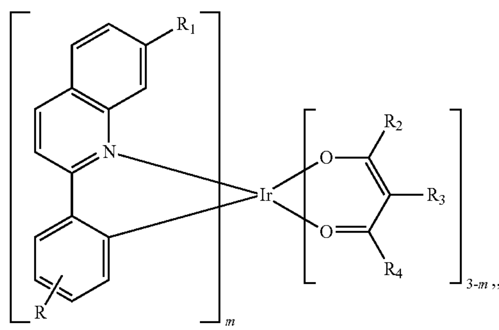
In one embodiment, the compound has the formula:

Formula II



In one embodiment, the compound has the formula:

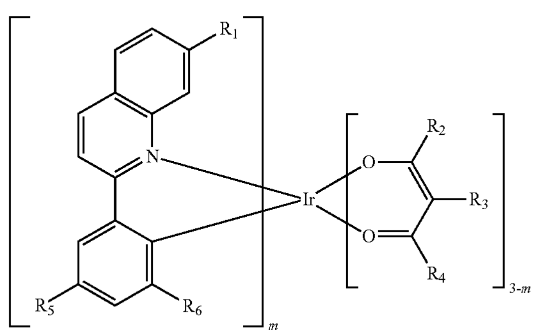
Formula II



wherein R_1 is selected from the group consisting of alkyl, cycloalkyl, and combinations thereof. In one embodiment, m is 2.

In one embodiment, the compound has the formula:

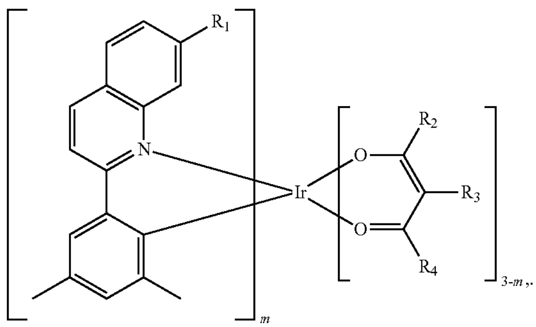
Formula III



wherein R_5 and R_6 are alkyl.

In one embodiment, the compound has the formula:

Formula IV



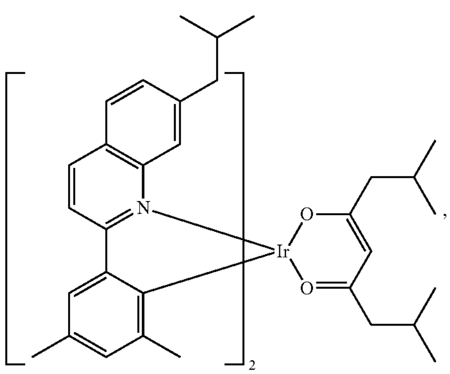
In one embodiment, R_2, R_3, and R_4 are independently selected from the group consisting of aryl, alkyl, hydrogen, deuterium, and combinations thereof. In another embodiment, R_2, R_3, and R_4 are independently selected from the group consisting of: methyl, $CH(CH_3)_2$, $CH_2CH(CH_3)_2$, phenyl, cyclohexyl, and combinations thereof.

In one embodiment, R_1 is alkyl. In one aspect, R_1 is selected from the group consisting of: $CH_2CH(CH_3)_2$, cyclopentyl, $CH_2C(CH_3)_3$, and cyclohexyl. In one embodiment, R_1 is $CH_2CH(CH_3)_2$.

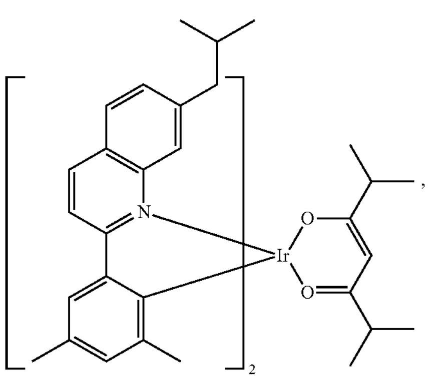
In one embodiment, R_3 is hydrogen or deuterium and R_2 and R_4 are independently selected from $CH(CH_3)_2$ and $CH_2CH(CH_3)_2$.

In one embodiment, the compound is selected from the group consisting of:

Compound 1



Compound 2



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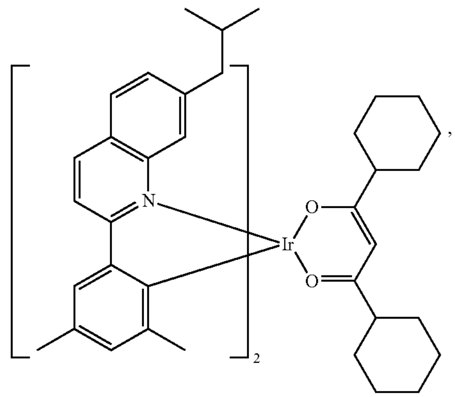
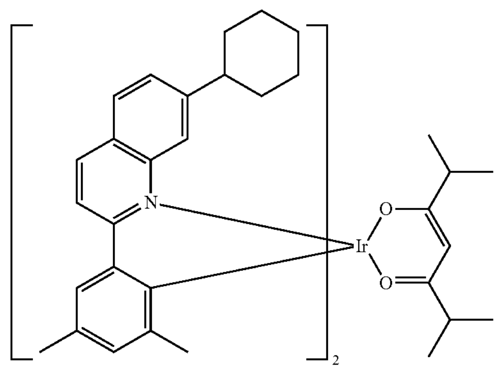
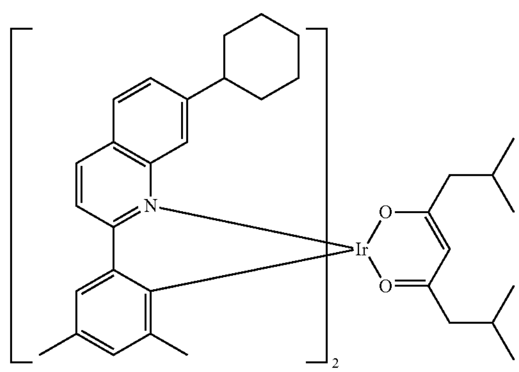
Compound 3



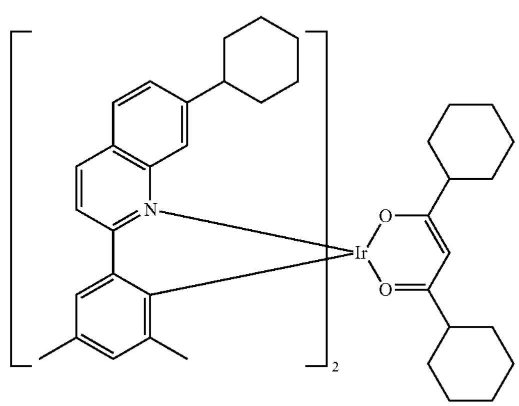
Compound 4



Compound 5



Compound 6



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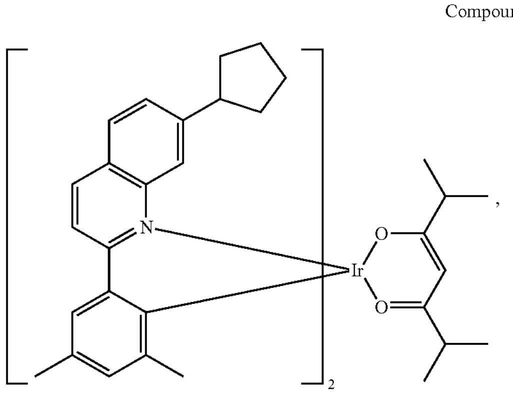
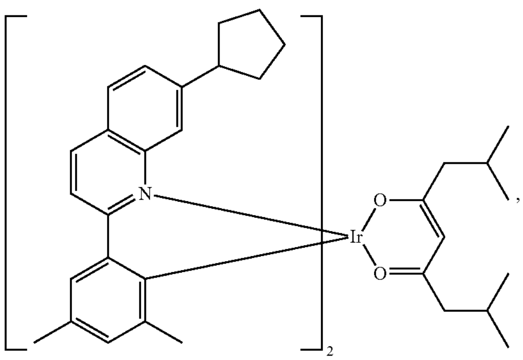
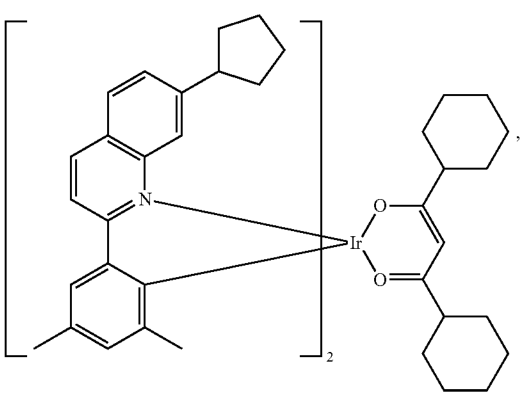
Compound 7



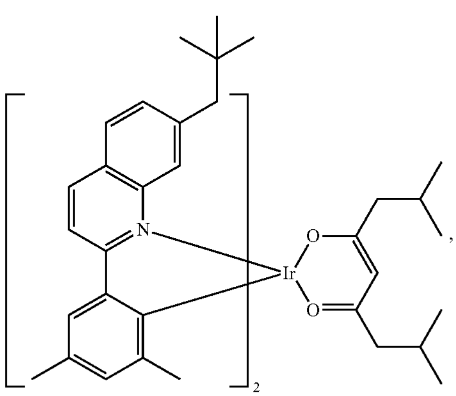
Compound 8



Compound 9



Compound 10



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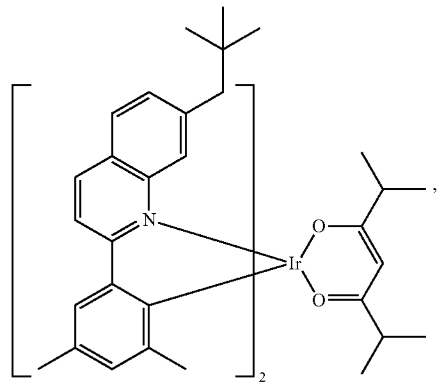
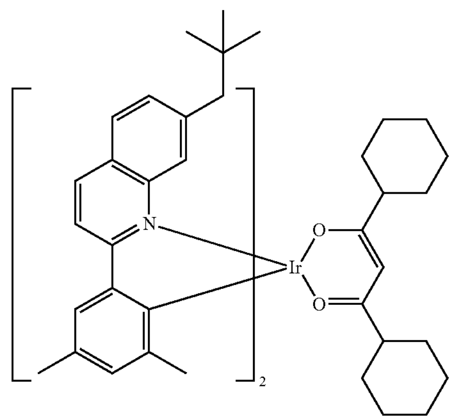
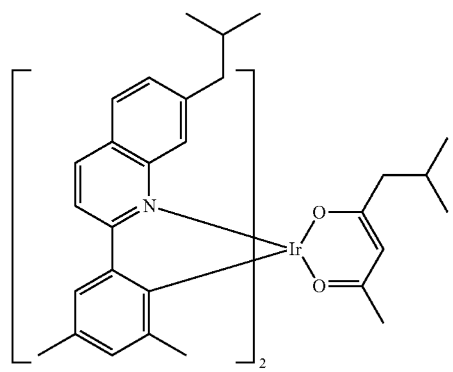
Compound 11



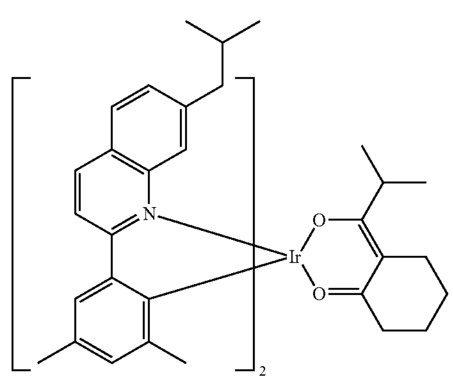
Compound 12



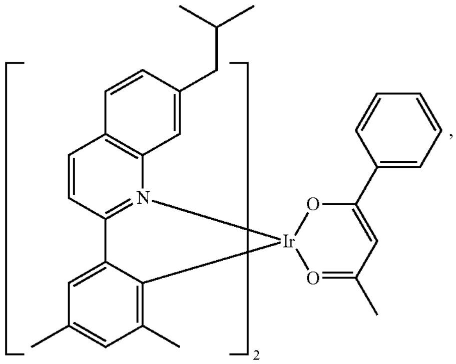
Compound 13



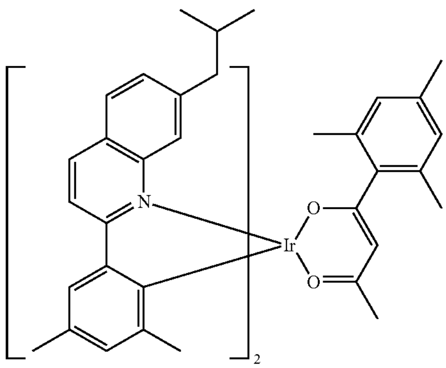
Compound 14



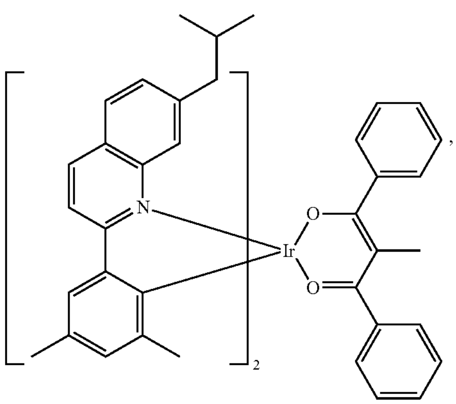
Compound 15



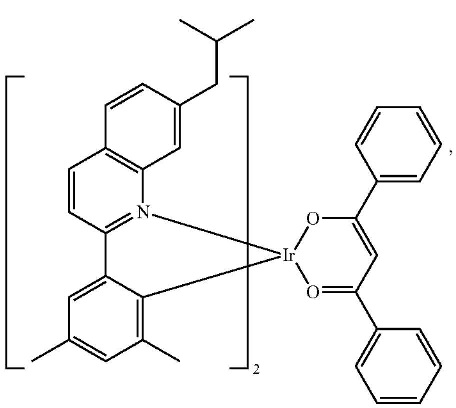
Compound 16



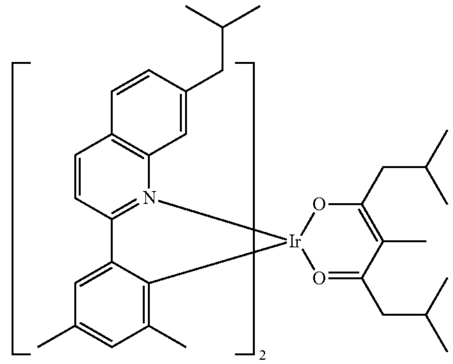
Compound 17



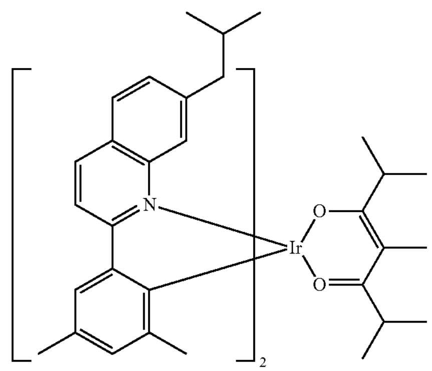
Compound 18



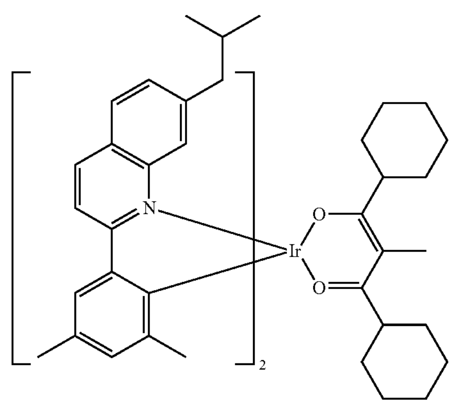
Compound 19



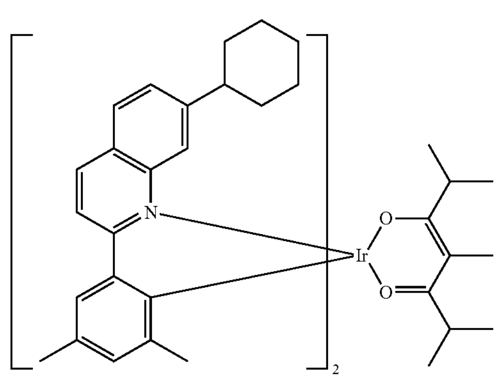
Compound 20



Compound 21



Compound 22



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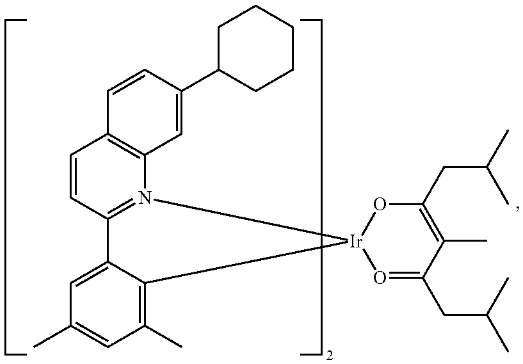
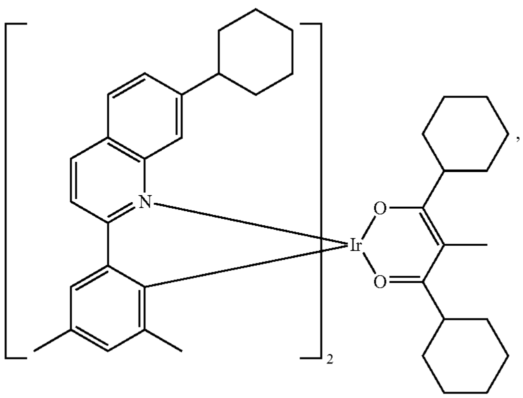
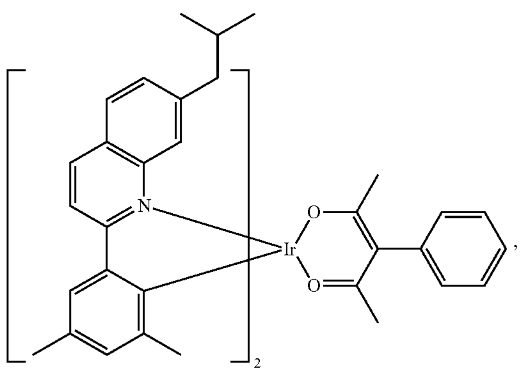
Compound 23



Compound 24



Compound 25



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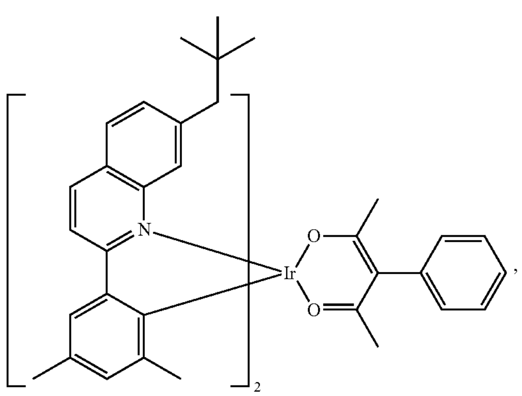

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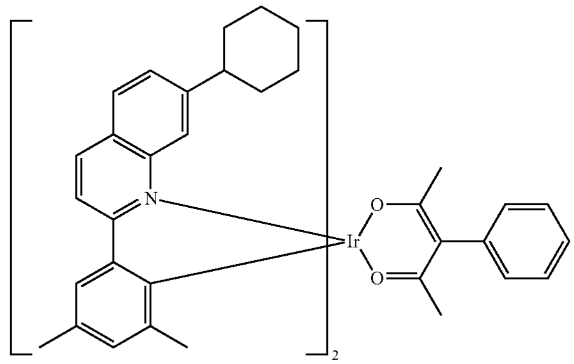
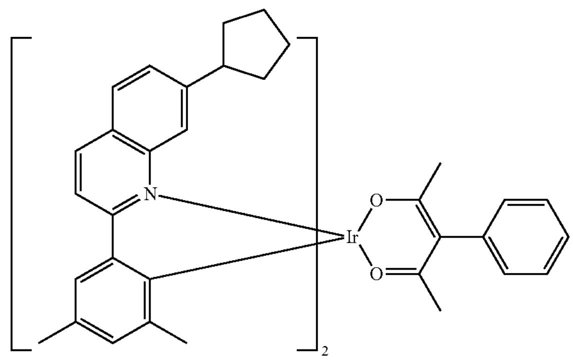
Compound 27



Compound 28



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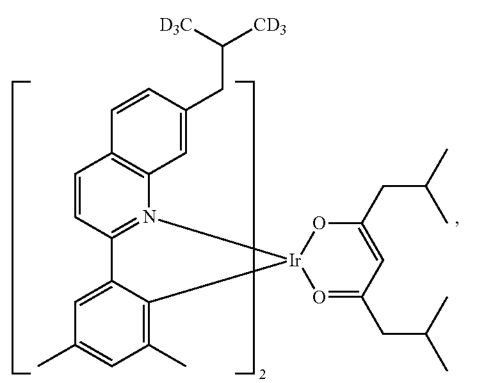
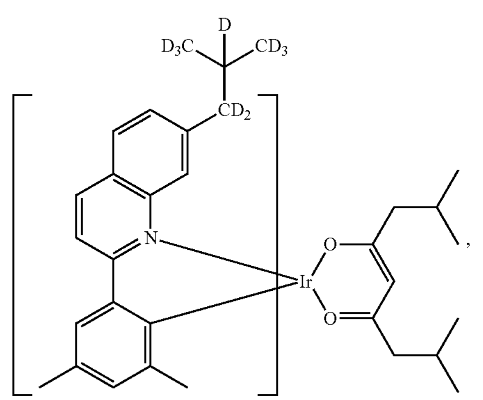


Compound 30



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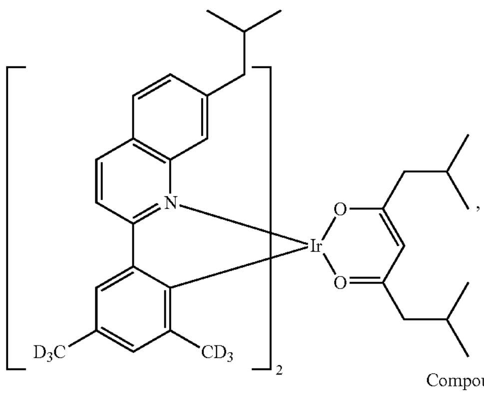
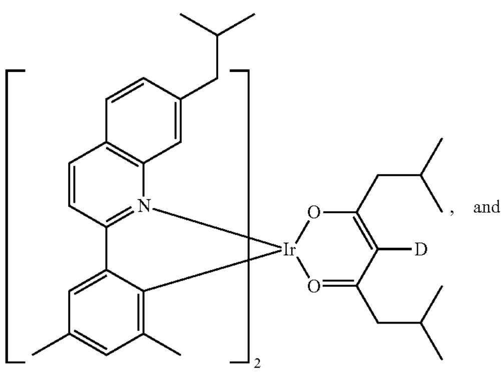
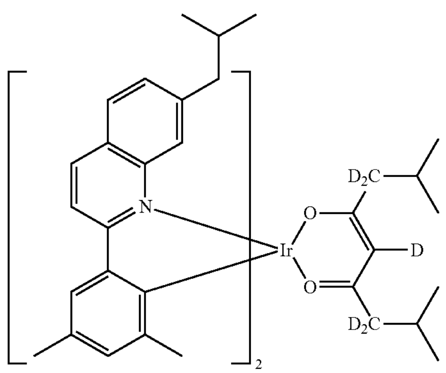
Compound 31



Compound 32

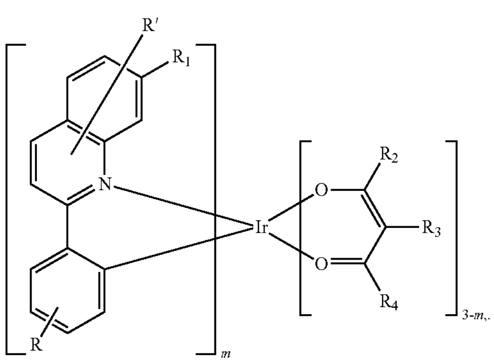


Compound 33



In one aspect, a first device is provided. The first device comprises a first organic light emitting device, further comprising an anode, a cathode and an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

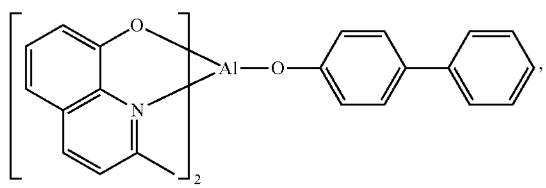
Formula I

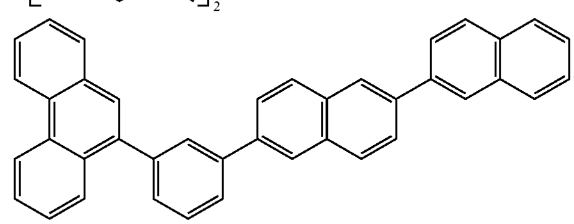


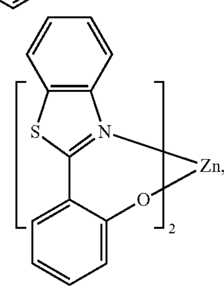
In the compound of Formula I, R_1 is selected from the group consisting of alkyl, cycloalkyl, heteroalkyl, aryl, heteroaryl, and combinations thereof, wherein R_1 has four or more carbon atoms. R, R', R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfanyl, sulfonyl, phosphino, and combinations thereof. At least one of the R_2, R_3 and R_4 has two or more carbon atoms, and R and R' may represent mono, di, ti, tetra substitution, or no substitution. Two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring, and m is 1 or 2.

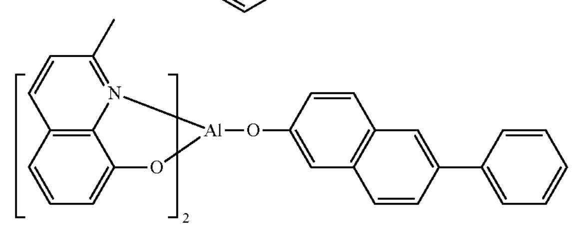
In one aspect, the first device is a consumer product. In one aspect, the first device is an organic light-emitting device. In one aspect, the first device comprises a lighting panel.

In one aspect, the organic layer further comprises a host. In one aspect, the host comprises a metal 8-hydroxyquinolate. In one aspect, the host is selected from the group consisting of:









and combinations thereof.

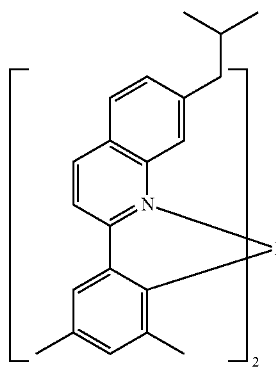
Device Examples

All device examples were fabricated by high vacuum ($<10^{-7}$ Torr) thermal evaporation (VTE). The anode electrode is 1200 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1000 Å of Al. All devices were encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H_2O and O_2) immediately after fabrication, and a moisture getter was incorporated inside the package.

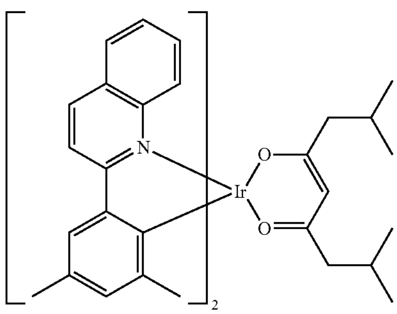
The organic stack of the Device Example consisted of sequentially, from the ITO surface, 100 Å of hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD) as the hole transporting later (HTL), 300 Å of host doped with 9% of Compound 1 or 2 as the emissive layer (EML), and 400 Å of Alq_3 (tris-8-hydroxyquinoline aluminum) as the ETL.

As used herein, the following compounds have the following structures:

Compound A



Compound B



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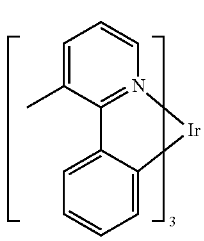
Compound C



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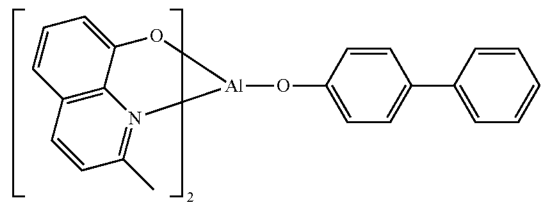
Compound D



The device structures are provided in Table 1, and the corresponding device data is provided in Table 2.

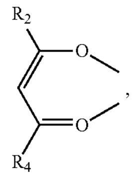
TABLE 1

VTE Phosphorescent OLEDs					
Device Example	HIL	HTL	EML(doping %)		ETL
Example 1	Compound C	NPD	Compound D	Compound 1 (9%)	Alq3
Example 2	Compound C	NPD	Compound D	Compound 2 (9%)	Alq3
Comparative Example 1	Compound C	NPD	Compound D	Compound A (9%)	Alq3
Comparative Example 2	Compound C	NPD	Compound D	Compound B (9%)	Alq3

TABLE 2

VTE Device Data									
	CIE				At 1000 cd/m2				
Device Example	λmax	FWHM/nm	CIE (x)	CIE (y)	V [V]	cd/A	EQE %	lm/W	cd/A/EQE
Example 1	612	52	0.652	0.346	7.5	28.9	21.2	12.0	1.36
Example 2	618	52	0.656	0.342	7.7	26.4	20.3	10.7	1.30
Comparative Example 1	616	60	0.656	0.342	8.4	26.2	20.8	9.8	1.26
Comparative Example 2	620	58	0.662	0.335	7.4	21.9	18.9	9.3	1.16

It can be seen from Table 2 that the device examples containing compounds of Formula I, such as Compounds 1 and 2, show higher luminance efficiency and extremely narrow emission spectra versus the Comparative Examples 1 and 2, which have smaller alkyl groups on either the phenylquinoline or the acac-type ligand (acac is acetylacetone). Both Compound A and Compound 1 have a four carbon alkyl substituent on the 7-position of the heterocyclic ring. But, Compound A in Comparative Example 1 contains ligand



where R_2 and R_4 are alkyl groups with one carbon atom.

It has been unexpectedly discovered, that as the carbon chain length of R_2 and R_4 increases from one carbon to two or three carbons, the luminance efficiency increases and the FWHM (full width at half maximum) decreases in devices incorporating these longer carbon chains (i.e. compounds of Formula I). For example, using Compound 2 in Device Example 2, the luminance efficiency of Example 2 increases from 26.2 cd/A to 26.4 cd/A and the FWHM decreases from 60 nm to 52 nm. As the carbon chain length of R_2 and R_4 increases from three to four in Compound 1 in Device Example 1, the luminance of Device Example 1 increases to 28.9 cd/A and the FWHM is a narrow 52 nm. Furthermore, Comparative Example 2 contains Compound B which has the same acac-type ligand as in Compound 1 in device example 1. However, Compound B in Comparative Example 2 does not have any alkyl substitution on the 7 position of the heterocyclic ring with four or more carbons in the alkyl group, whereas Compound 1 does have such an alkyl group. The luminance efficiency of Compound 1 in Device Example 1 is 28.9 cd/A compared to 21.9 cd/A of Compound B in Comparative Example 2. Thus, unexpectedly, an iridium complex containing an acac-type ligand having alkyl substituents with two or more carbons and phenylquinoline ligand having an alkyl group with four or more carbons at the 7 position created a synergistic combination of properties that makes compounds of Formula I useful in OLED devices.

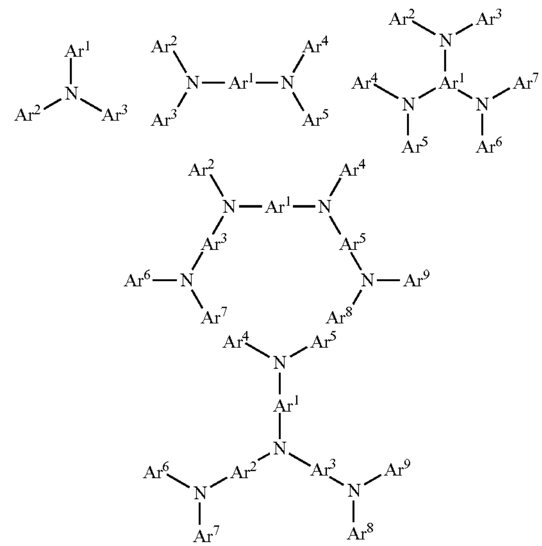
Combination with Other Materials

The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport layers, blocking layers, injection layers, electrodes and other layers that may be present. The materials described or referred to below are non-limiting examples of materials that may be useful in combination with the compounds disclosed herein, and one of skill in the art can readily consult the literature to identify other materials that may be useful in combination.

HIL/HTL:

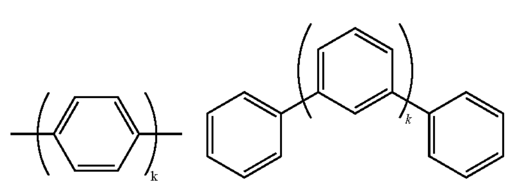
A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphryin derivative; an aromatic amine derivative; an indolocarbazole derivative; a polymer containing fluorohydrocarbon; a polymer with conductivity dopants; a conducting polymer, such as PEDOT/PSS; a self-assembly monomer derived from compounds such as phosphonic acid and sliane derivatives; a metal oxide derivative, such as MoO_x; a p-type semiconducting organic compound, such as 1,4,5,8,9,12-Hexaazatriphenylenehexacarbonitrile; a metal complex, and a cross-linkable compounds.

Examples of aromatic amine derivatives used in HIL or HTL include, but not limit to the following general structures:



Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, cbrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each Ar is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, Ar^1 to Ar^9 is independently selected from the group consisting of



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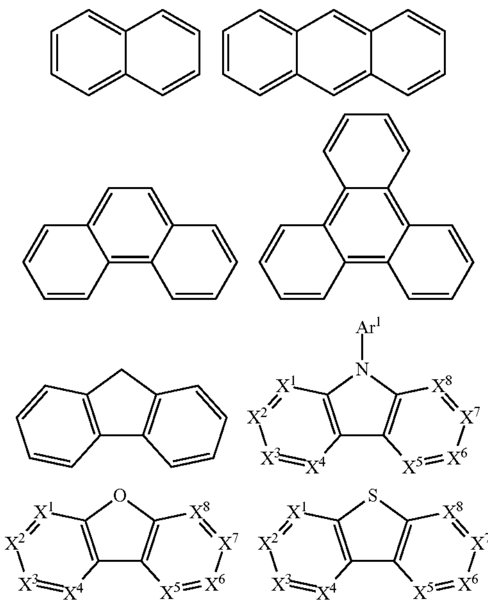
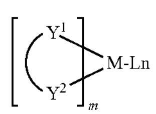


k is an integer from 1 to 20; X^1 to X^8 is C (including CH) or N; Ar^1 has the same group defined above.

Examples of metal complexes used in HIL or HTL include, but not limit to the following general formula:



M is a metal, having an atomic weight greater than 40; $(Y^1\text{-}Y^2)$ is a bidentate ligand, Y^1 and Y^2 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, $(Y^1\text{-}Y^2)$ is a 2-phenylpyridine derivative.

In another aspect, $(Y^1\text{-}Y^2)$ is a carbene ligand.

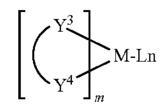
In another aspect, M is selected from Ir, Pt, Os, and Zn.

In a further aspect, the metal complex has a smallest oxidation potential in solution vs. Fc^+/Fc couple less than about 0.6 V.

Host:

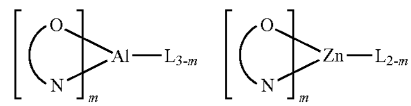
The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant. While the Table below categorizes host materials as preferred for devices that emit various colors, any host material may be used with any dopant so long as the triplet criteria is satisfied.

Examples of metal complexes used as host are preferred to have the following general formula:



M is a metal; $(Y^3\text{-}Y^4)$ is a bidentate ligand, Y^3 and Y^4 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, the metal complexes are:



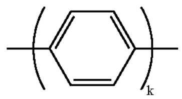
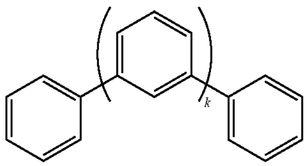
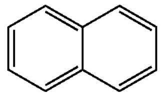
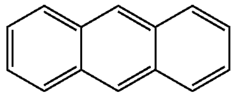
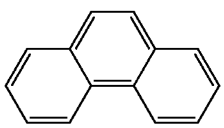
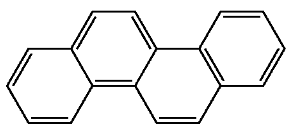
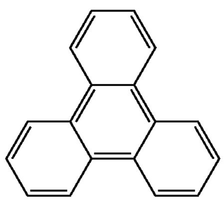
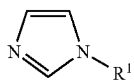
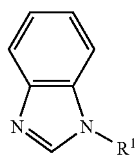
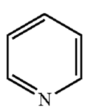
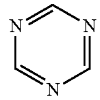
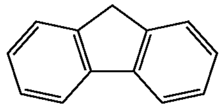
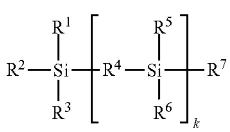
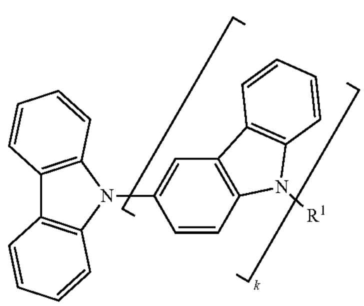
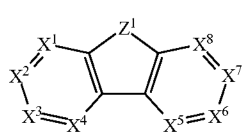
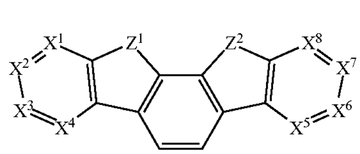
(O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

In another aspect, M is selected from Ir and Pt.

In a further aspect, $(Y^3\text{-}Y^4)$ is a carbene ligand.

Examples of organic compounds used as host are selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atome, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each group is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfanyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, host compound contains at least one of the following groups in the molecule:

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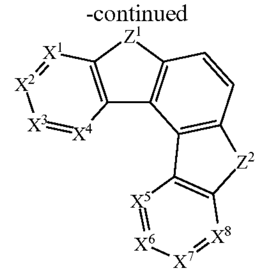
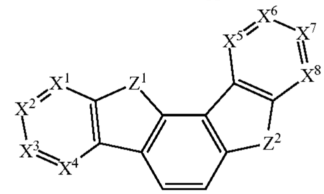
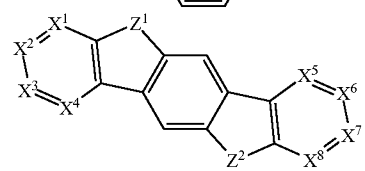
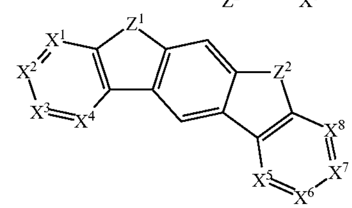





R^1 to R^7 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfonyl, sulfnyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

X^1 to X^8 is selected from C (including CH) or N.

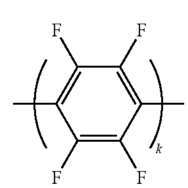
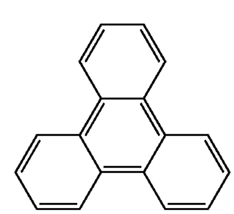
Z^1 and Z^2 is selected from NR^1, O, or S.

HBL:

A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED.

In one aspect, compound used in HBL contains the same molecule or the same functional groups used as host described above.

In another aspect, compound used in HBL contains at least one of the following groups in the molecule:

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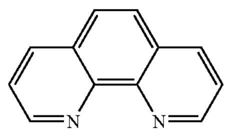
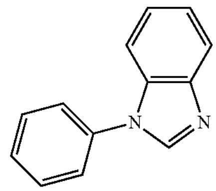
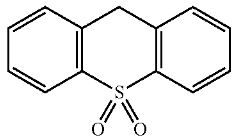
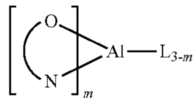






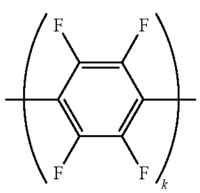


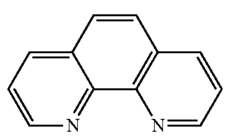
k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

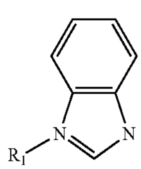
ETL:

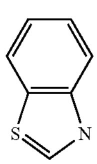
Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may be used as long as they are typically used to transport electrons.

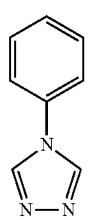
In one aspect, compound used in ETL contains at least one of the following groups in the molecule:

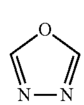


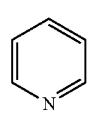


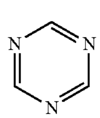


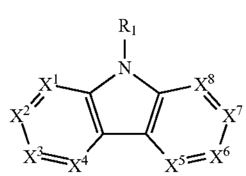


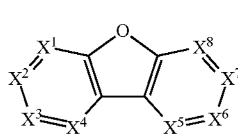


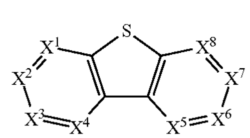












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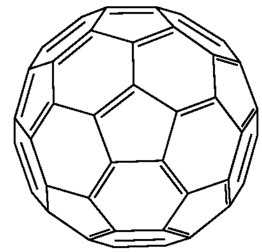
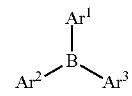




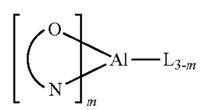
R^1 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

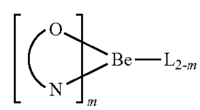
Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

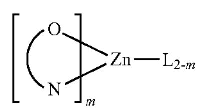
k is an integer from 0 to 20.

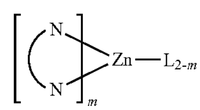
X^1 to X^5 is selected from C (including CH) or N.

In another aspect, the metal complexes used in ETL contains, but not limit to the following general formula:









(O—N) or (N—N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated.

In addition to and/or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 3 below. Table 3 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 3

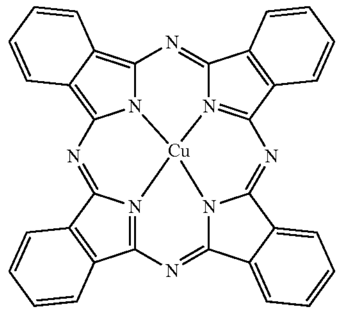
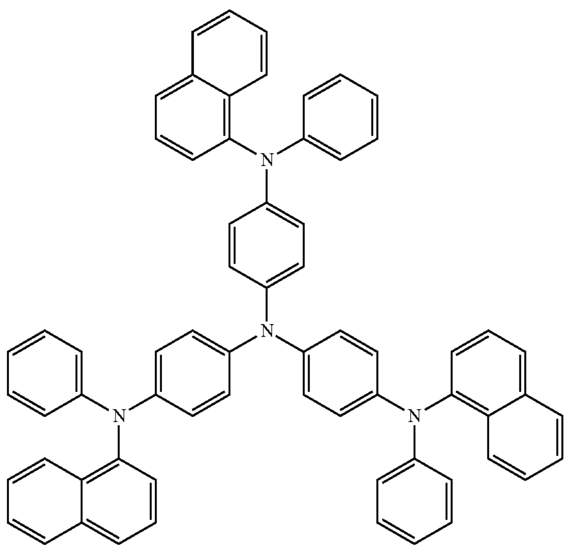
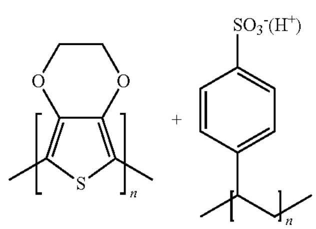
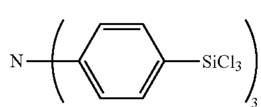
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole injection materials	
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_x Fluorohydrocarbon polymer	$-\!\!\left[CH_xF_y\right]_n\!\!-$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polypthiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and sliane SAMs		US20030162053

TABLE 3-continued

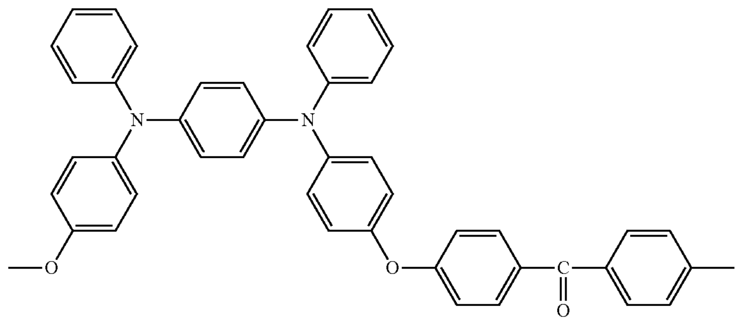
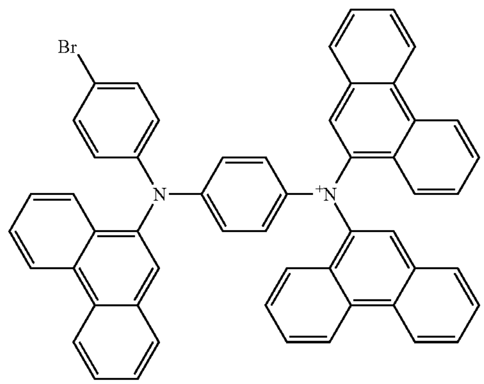
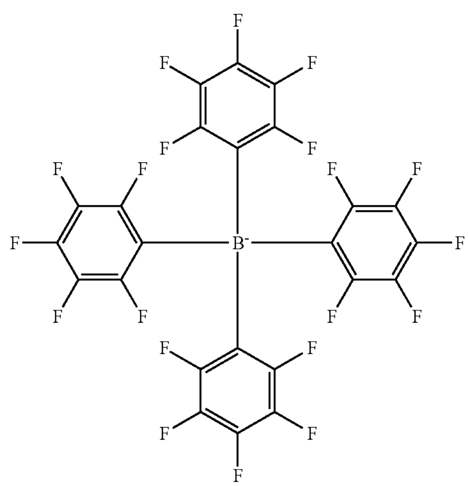
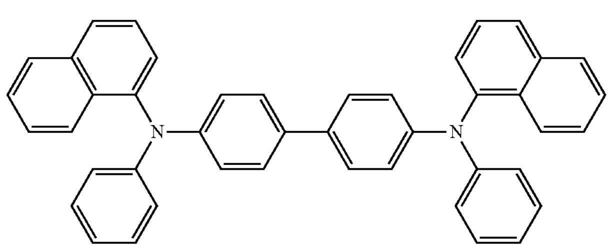
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triarylamine or polythiophene polymers with conductivity dopants	 and  	EP1725079A1
Organic compounds with conductive inorganic compounds, such as molybdenum and tungsten oxides	 + MoO_x	US20050123751 SID Symposium Digest, 37, 923 (2006) WO2009018009

TABLE 3-continued

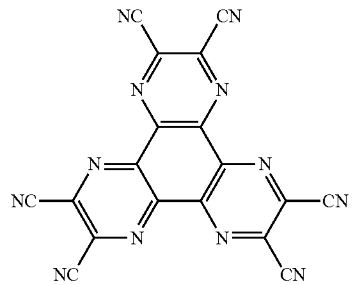
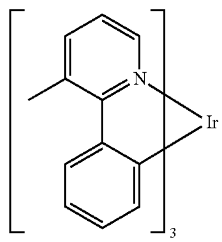
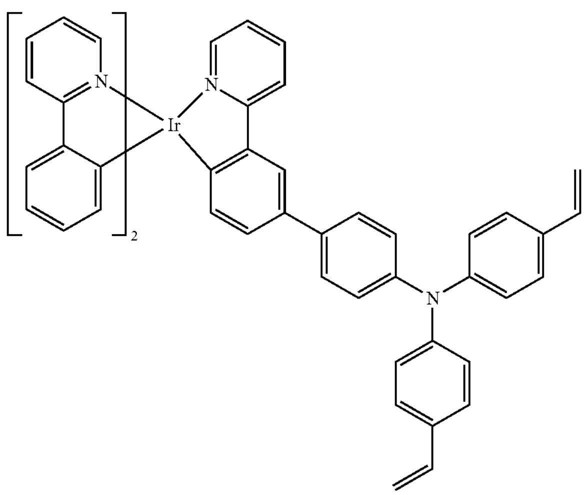
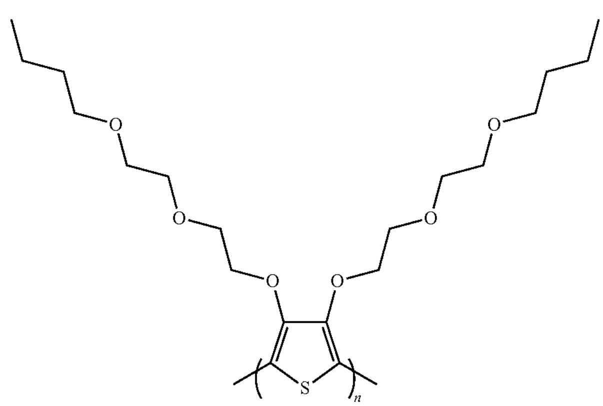
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
n-type semi-conducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
Polythiophene based polymers and copolymers		WO2011075644 EP2350216

TABLE 3-continued

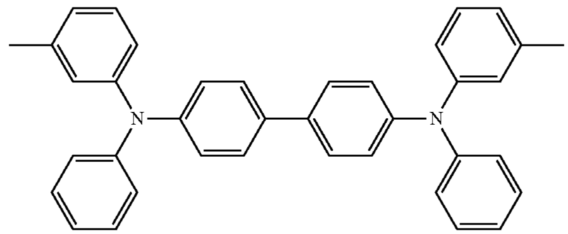
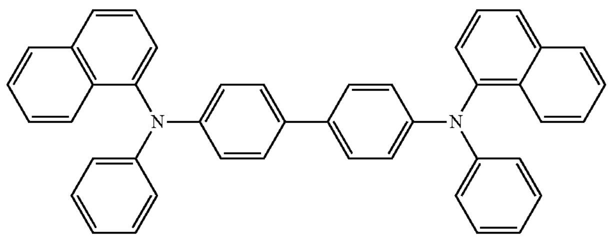
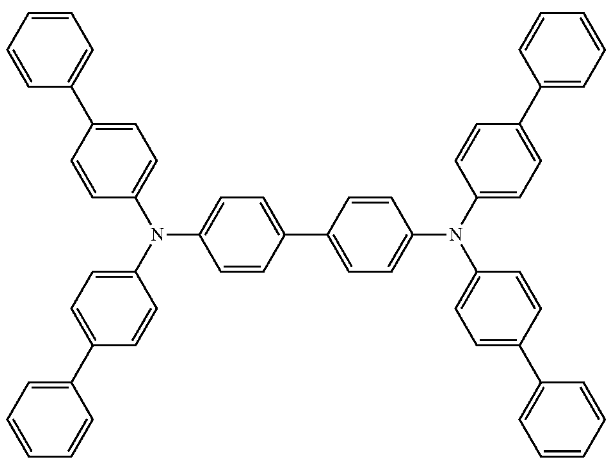
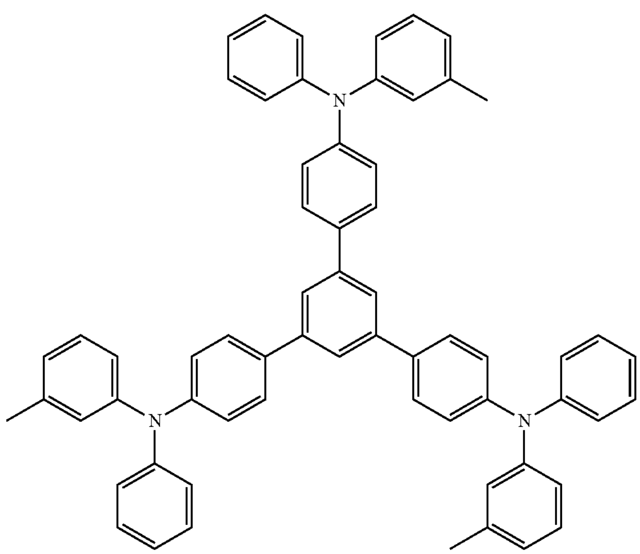
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
Hole transporting materials		
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		U.S. Pat. No. 5,061,569
		EP650955
		J. Mater. Chem. 3, 319 (1993)

TABLE 3-continued

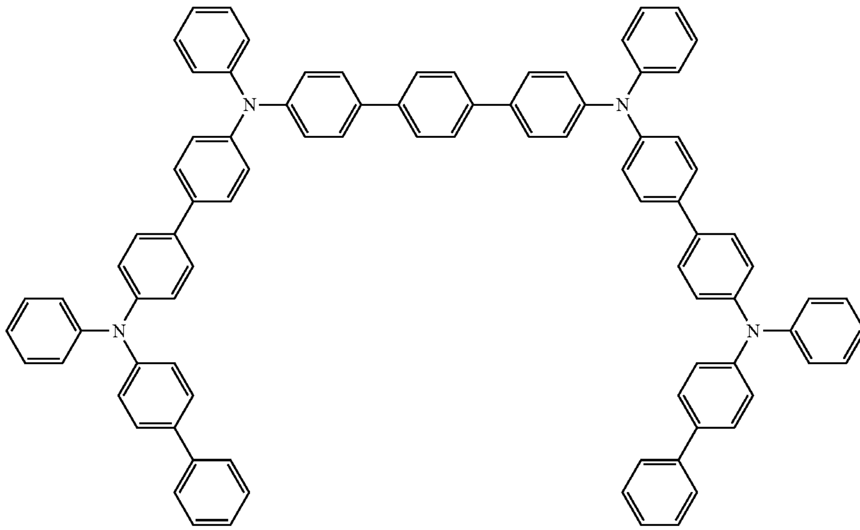
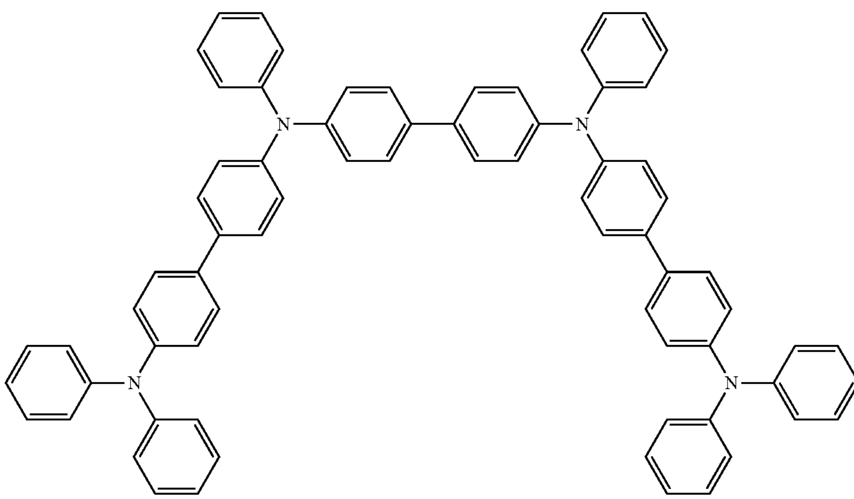
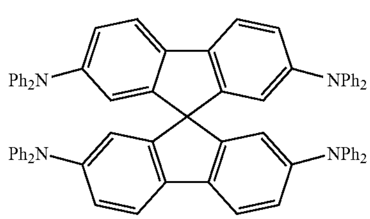
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
		Appl. Phys. Lett. 90, 183503 (2007)
Triaylamine on spirofluorene core		Synth. Met. 91, 209 (1997)

TABLE 3-continued

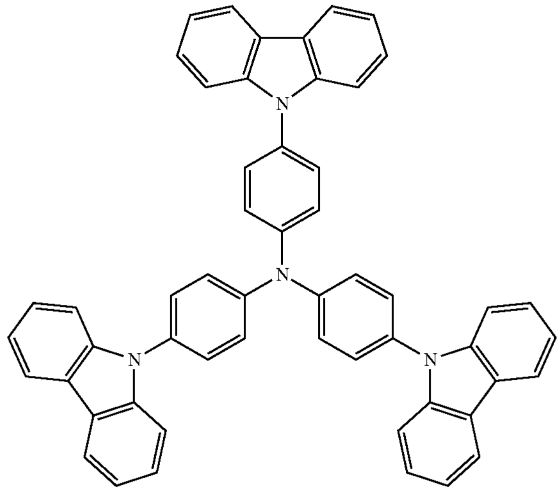
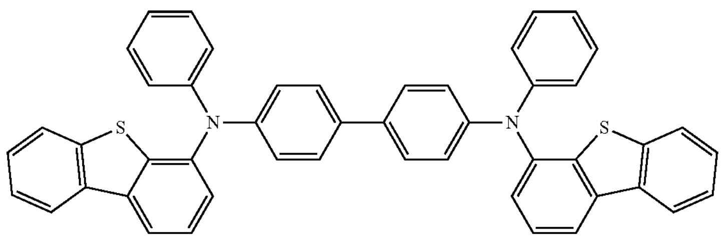
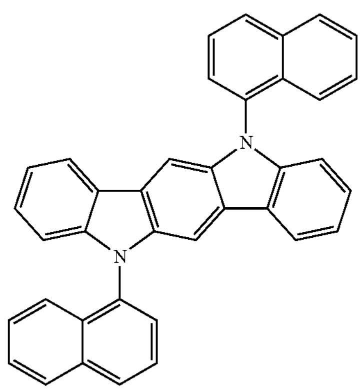
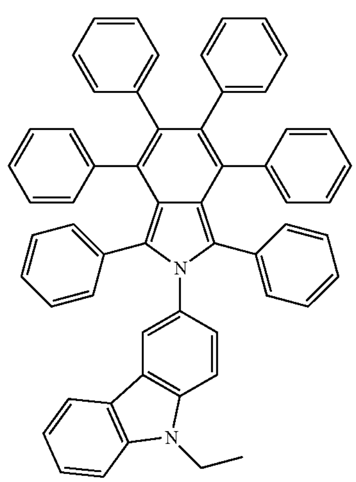
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzothiophene/(di)benzofuran		US20070278938, US20080106190 US20110163302
Indolo-carbazoles		Synth. Met 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)

TABLE 3-continued

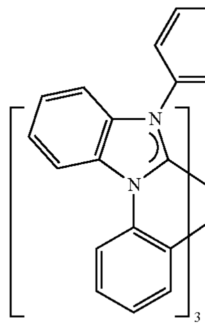
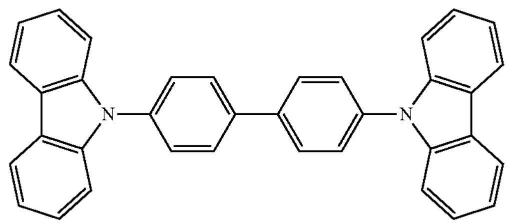
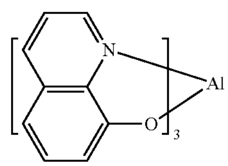
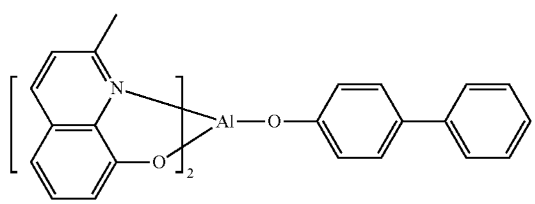
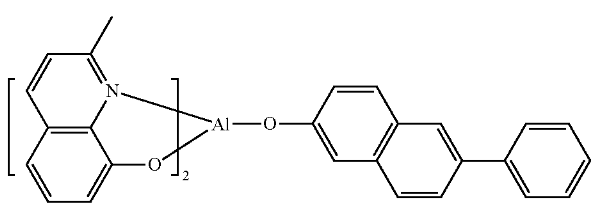
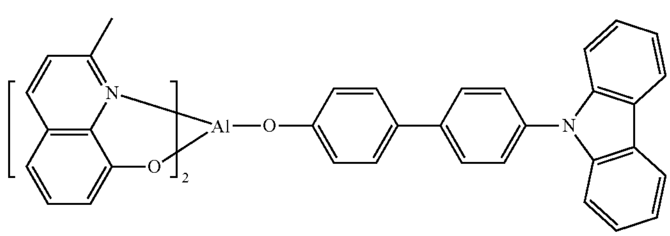
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal carbene complexes		US20080018221
Phosphorescent OLED host materials Red hosts		
Aryl-carbazoles		Appl. Phys. Lett. 78, 1622 (2001)
Metal 8-hydroxy-quinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002

TABLE 3-continued

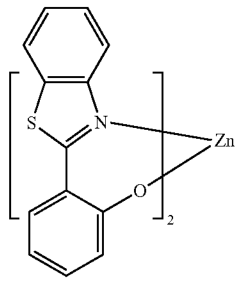
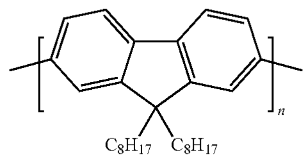
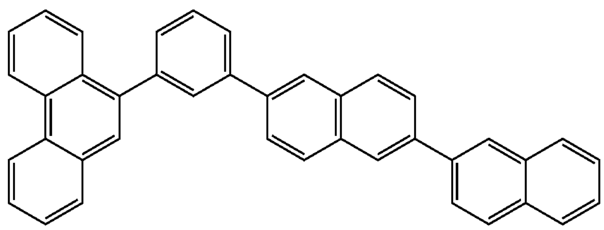
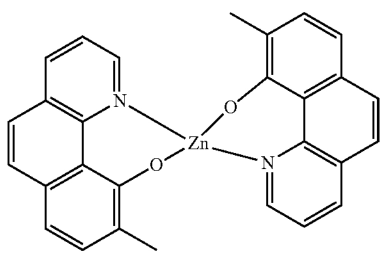
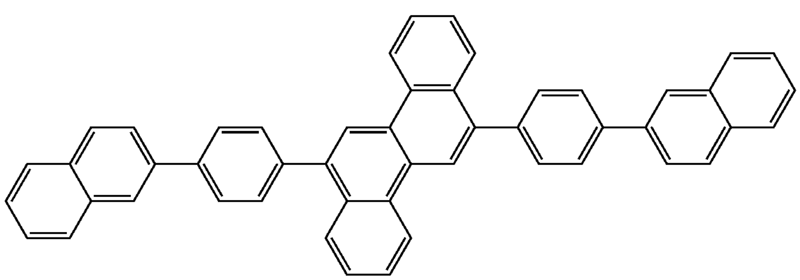
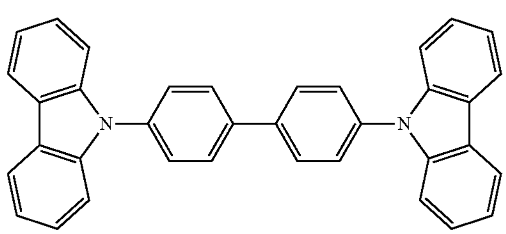
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal phenoxy-benzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., poly-fluorene)		Org. Electron, 1, 15 (2000)
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065
Zinc complexes		WO2010056066
Chrysene based compounds		WO2011086863
Green hosts		
Aryl-carbazoles		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 3-continued

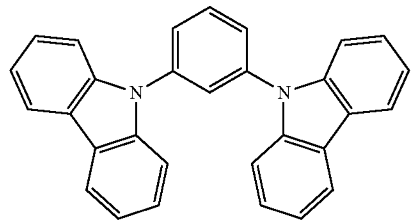
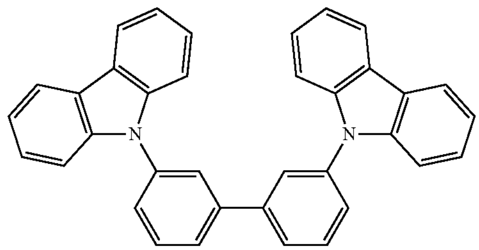
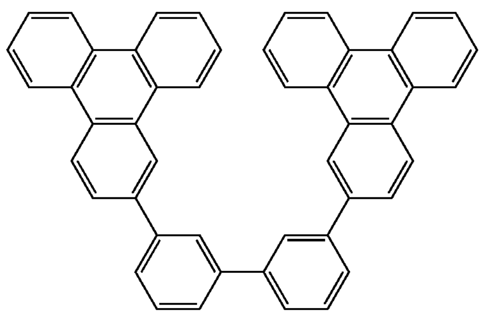
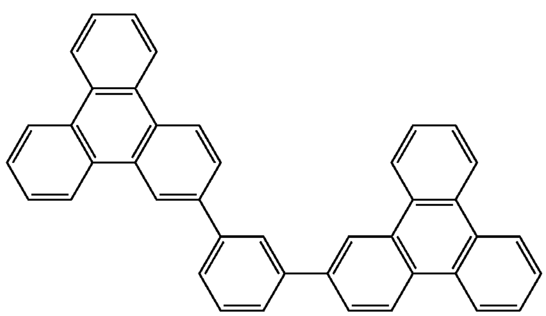
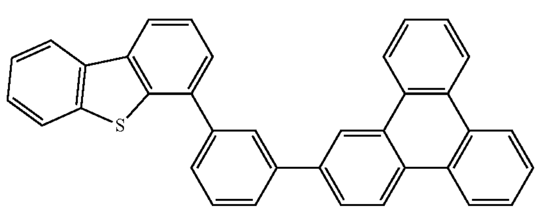
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US20030175553
		WO2001039234
Aryltri-phenylene compounds		US20060280965
		US20060280965
		WO2009021126

TABLE 3-continued

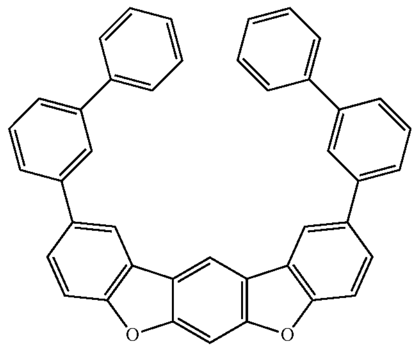
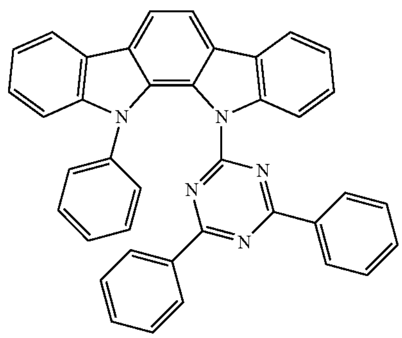
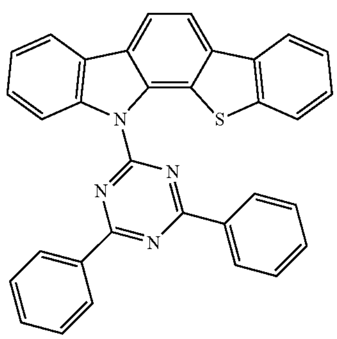
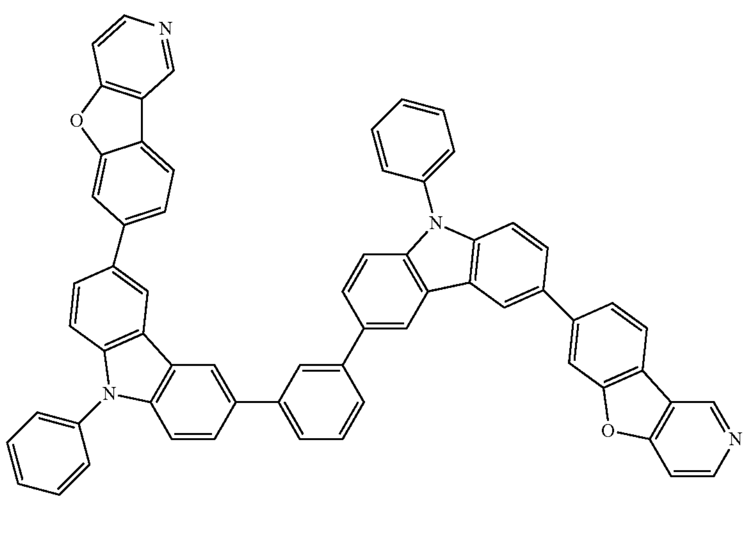
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Poly-fused heteroaryl compounds		US20090309488 US20090302743 US20100012931
Donor acceptor type molecules		WO2008056746
		WO2010107244
Aza-carbazole/ DBT/DBF		JP2008074939

TABLE 3-continued

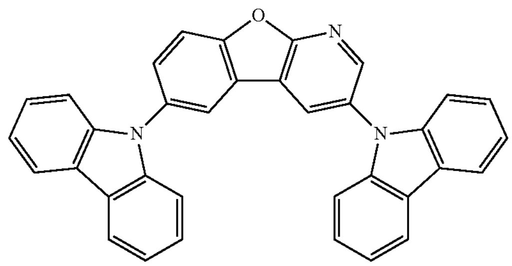
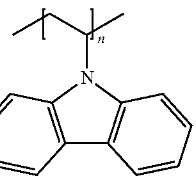
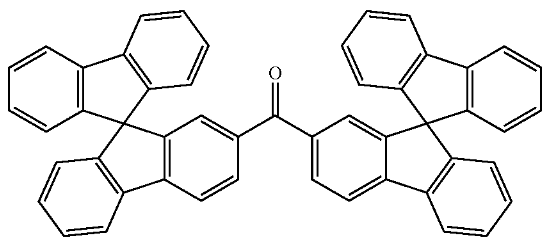
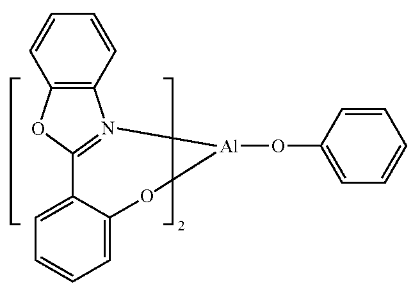
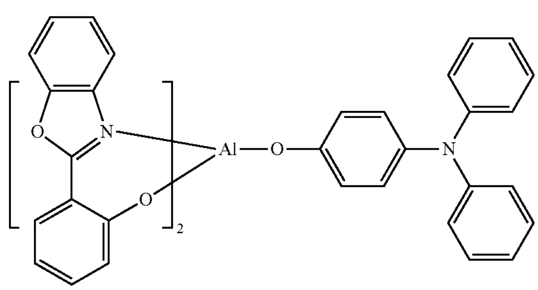
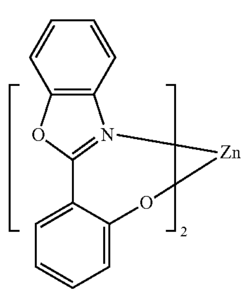
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20100187984
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)
Spirofluorene compounds		WO2004093207
Metal phenoxy-benzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610

TABLE 3-continued

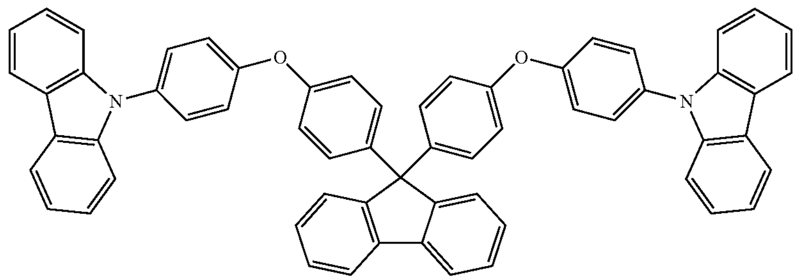
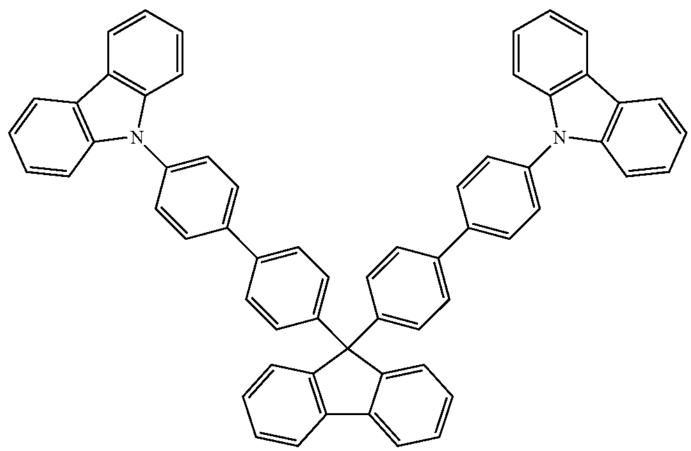
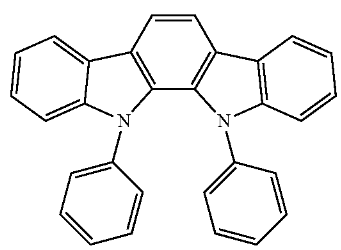
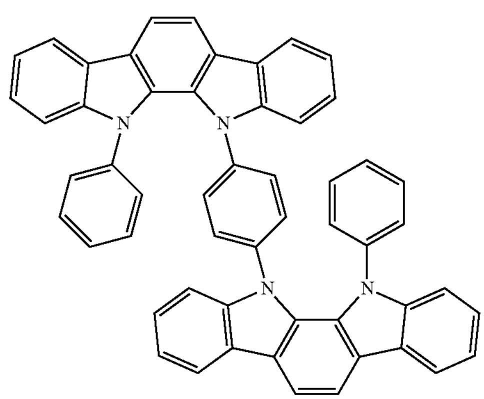
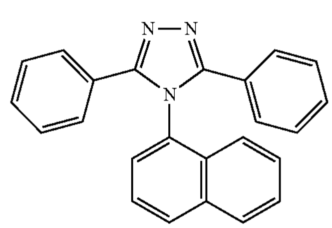
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene-carbazole compounds		JP2007254297
		JP2007254297
Indolo-cabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)

TABLE 3-continued

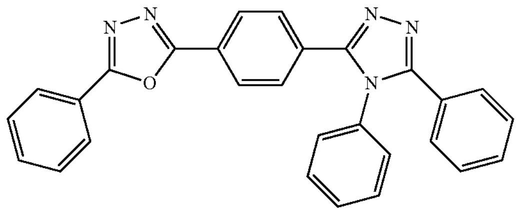
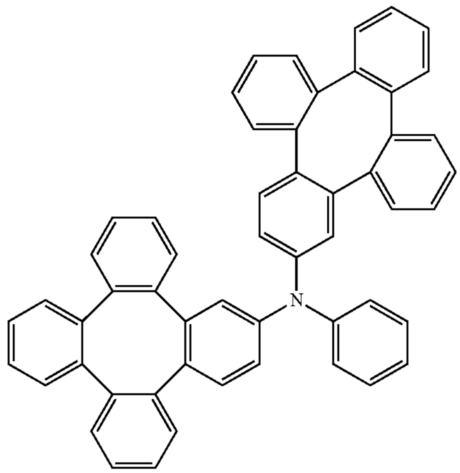
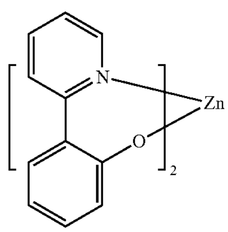
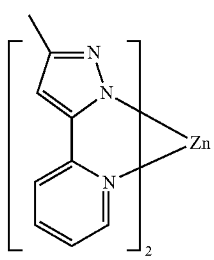
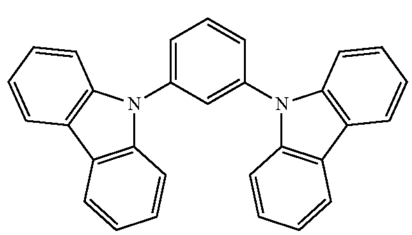
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2004107822
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with N^N ligands)		US20040137268, US20040137267
	Blue hosts	
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)

TABLE 3-continued

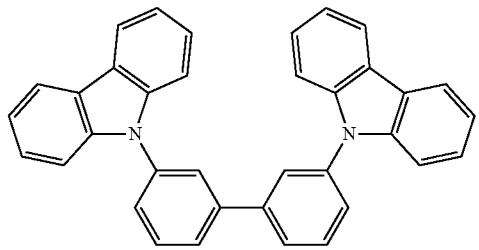
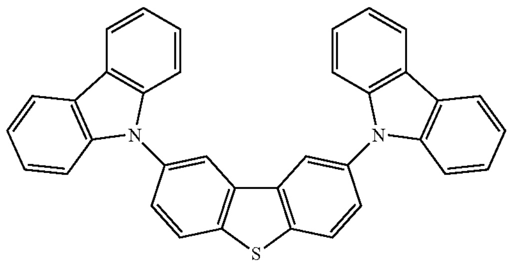
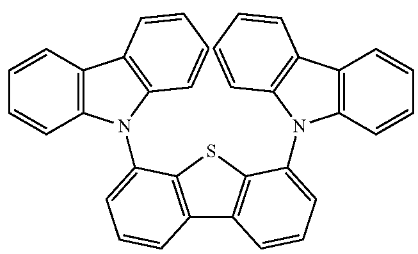
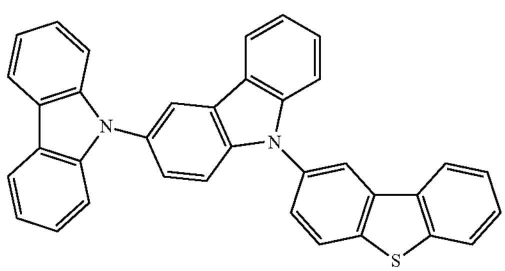
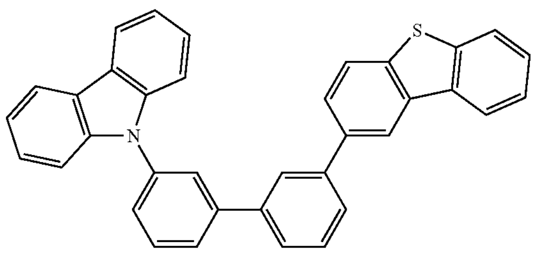
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US20070190359
Dibenzo-thiophene/Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330

TABLE 3-continued

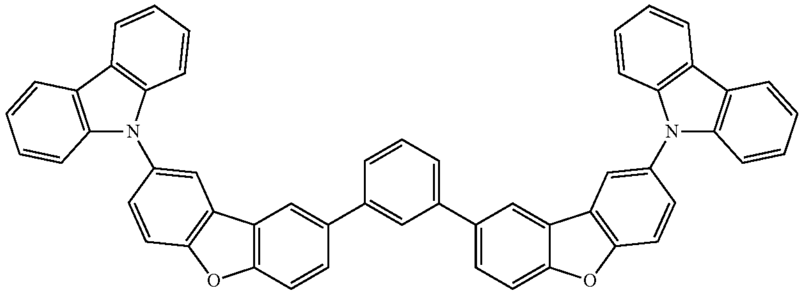
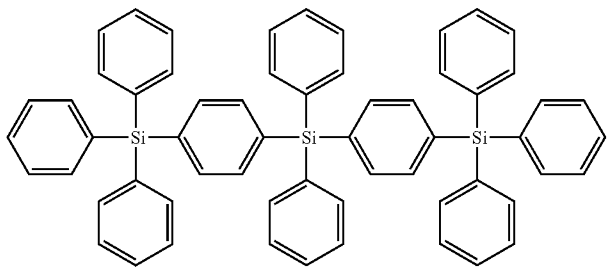
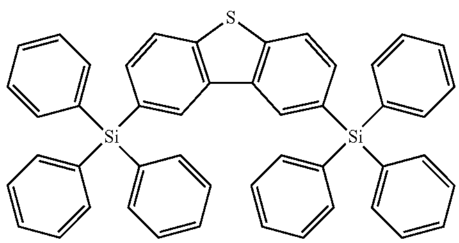
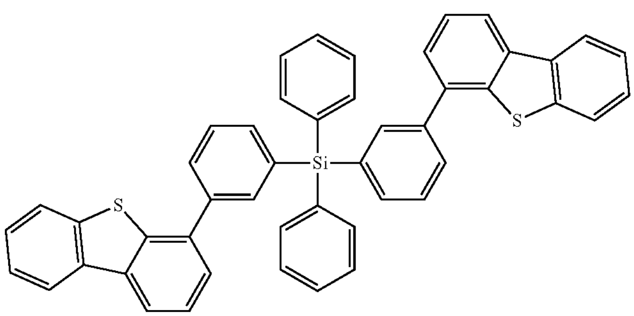
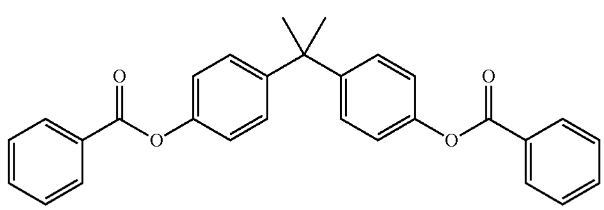
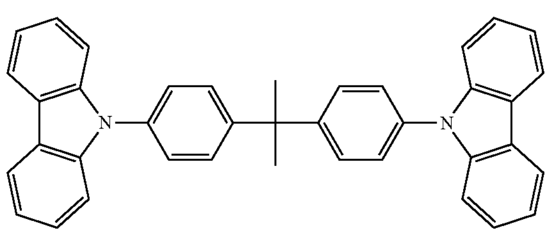
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20100084966
Silicon aryl compounds		US20050238919
		WO2009003898
Silicon/ Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
Carbazole linked by non-conjugated groups		US20040115476

TABLE 3-continued

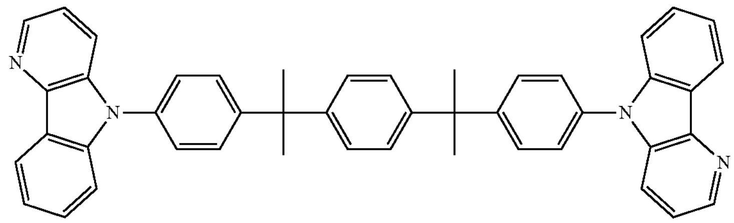
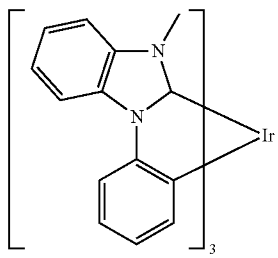
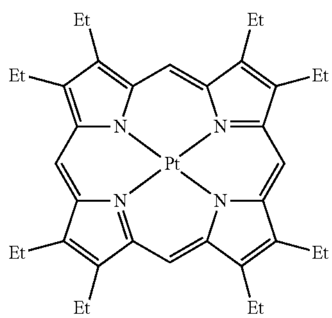
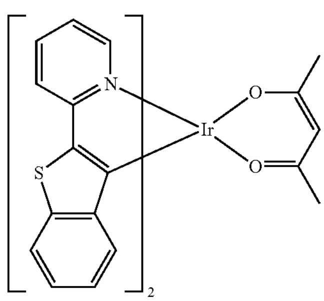
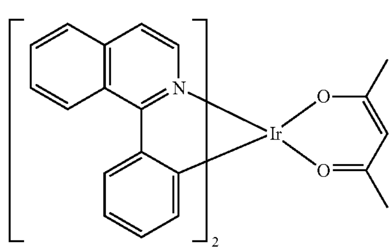
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Aza-carbazoles		US20060121308
High triplet metal organometallic complex		U.S. Pat. No. 7,154,114
	Phosphorescent dopants Red dopants	
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium (III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)
		US2006835469

TABLE 3-continued

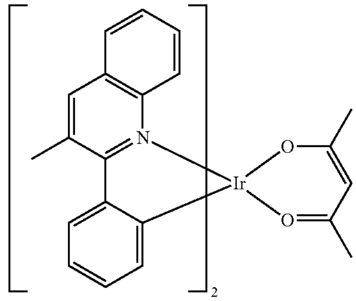
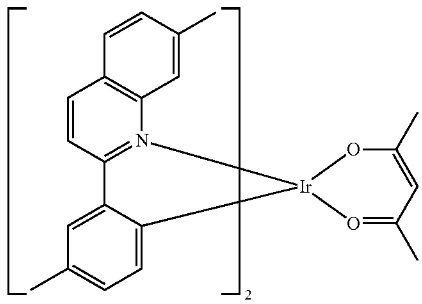
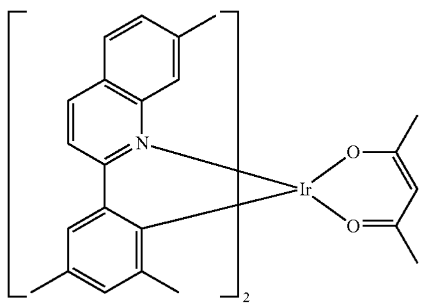
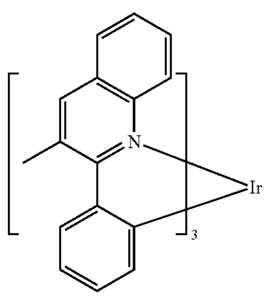
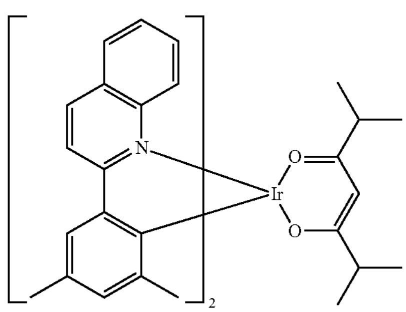
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US2006835469
		US20060202194
		US20060202194
		US20070087321
		US20080261076 US20100090591

TABLE 3-continued

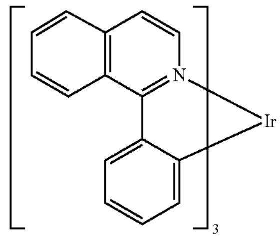
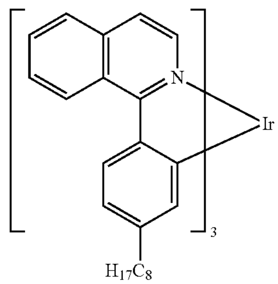
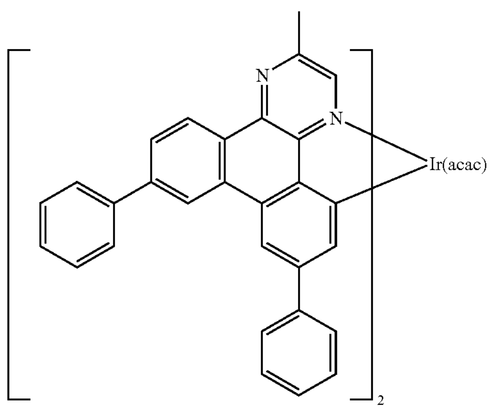
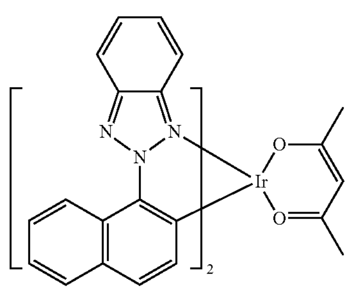
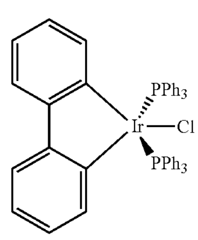
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842
		U.S. Pat. No. 7,232,618

TABLE 3-continued

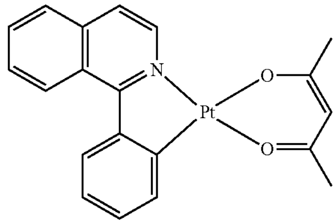
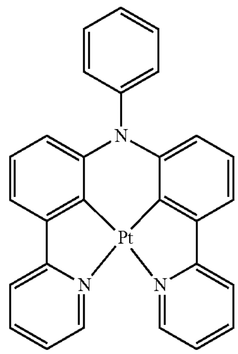
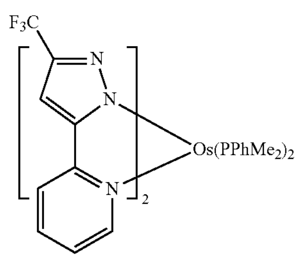
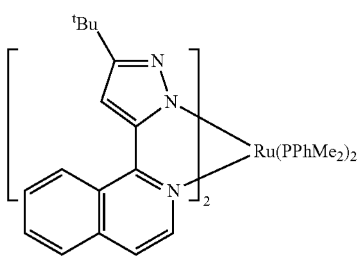
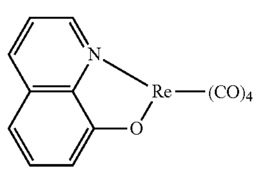
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Platinum (II) organometallic complexes		WO2003040257
		US20070103060
Osminum (III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium (II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673

TABLE 3-continued

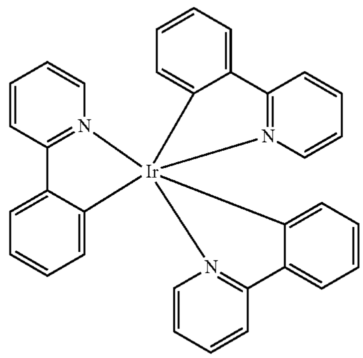
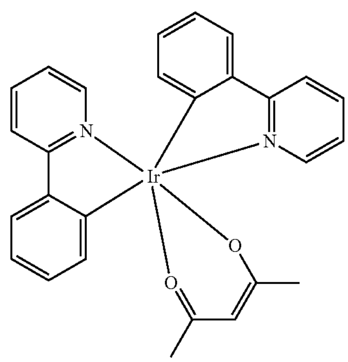
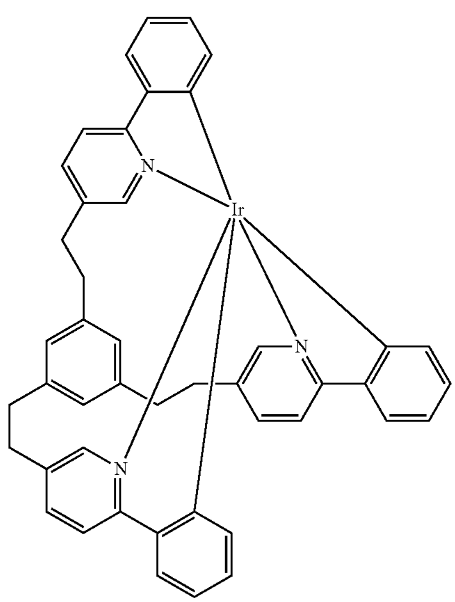
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Green dopants	
Iridium (III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US20020034656
		U.S. Pat. No. 7,332,232

TABLE 3-continued

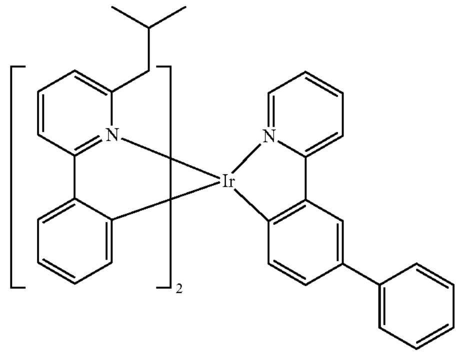
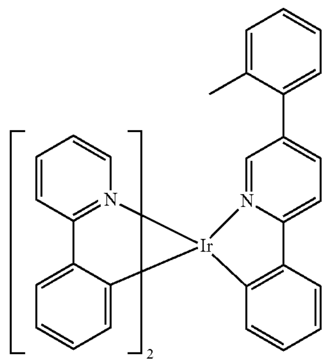
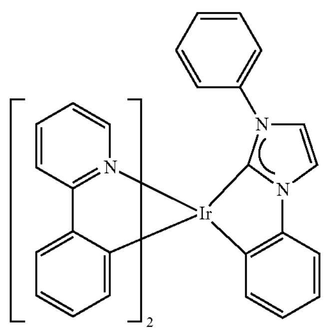
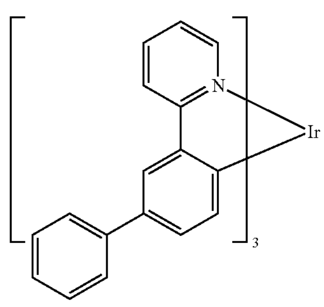
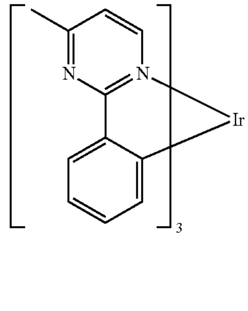
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US20090108737
		WO2010028151
		EP1841834B
		US20060127696
		US20090039776

TABLE 3-continued

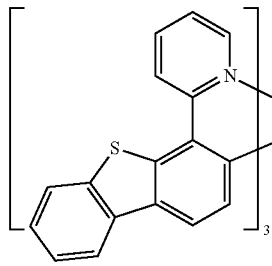
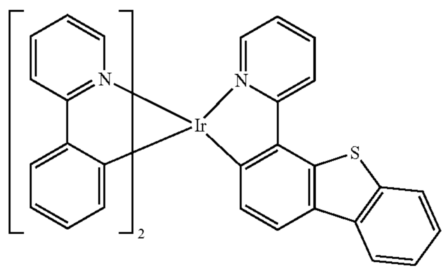
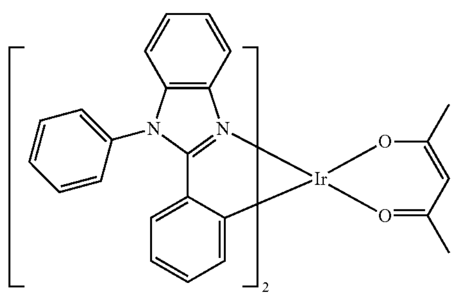
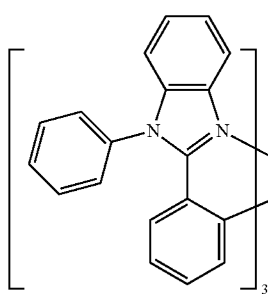
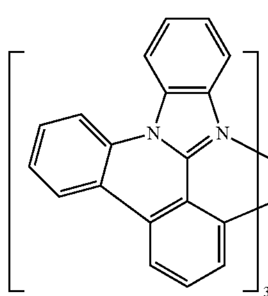
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 6,921,915
		US20100244004
		U.S. Pat. No. 6,687,266
		Chem. Mater. 16, 2480 (2004)
		US20070190359

TABLE 3-continued

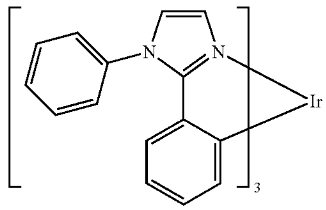
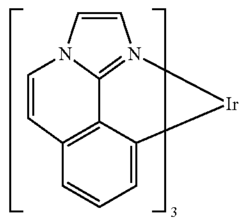
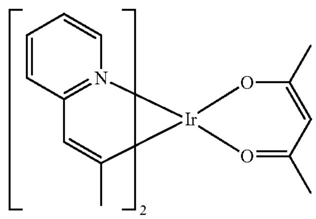
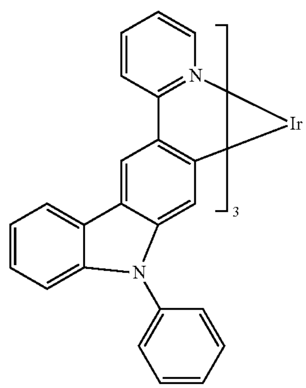
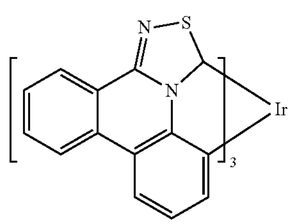
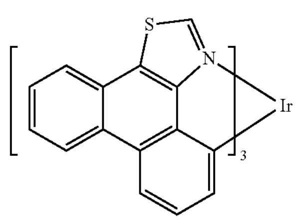
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060008670 JP2007123392
		WO2010086089, WO2011044988
		Adv. Mater. 16, 2003 (2004)
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846

TABLE 3-continued

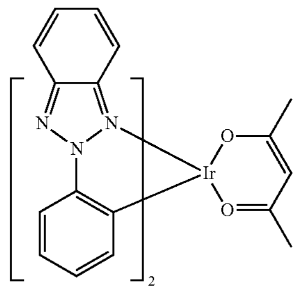
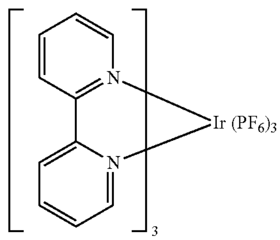
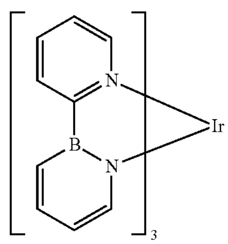
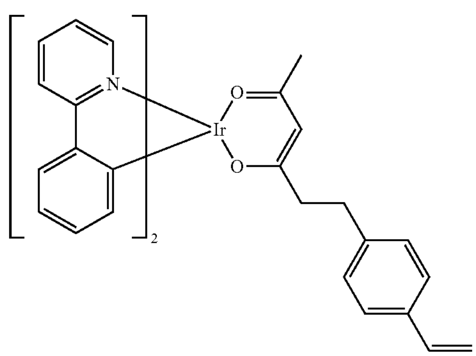
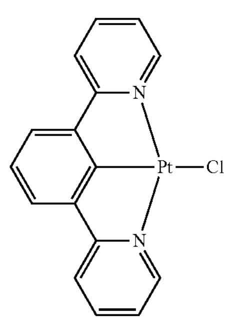
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		US20080015355
		US20010015432
		US20100295032
Monomer for polymeric metal organometallic compounds		U.S. Pat. No. 7,250,226, U.S. Pat. No. 7,396,598
Pt (II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)

TABLE 3-continued

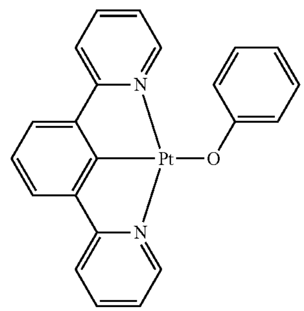
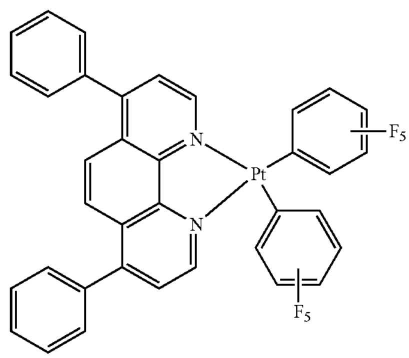
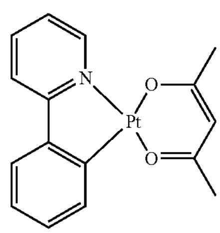
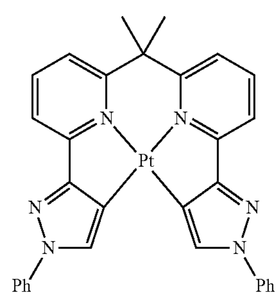
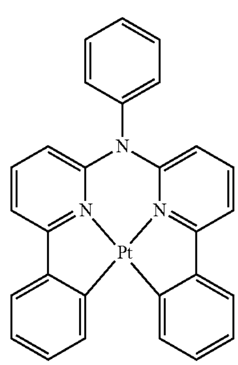
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635
		US20060182992 US20070103060

TABLE 3-continued

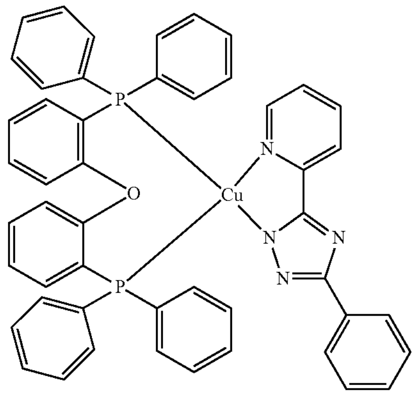
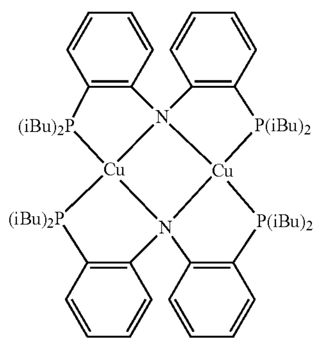
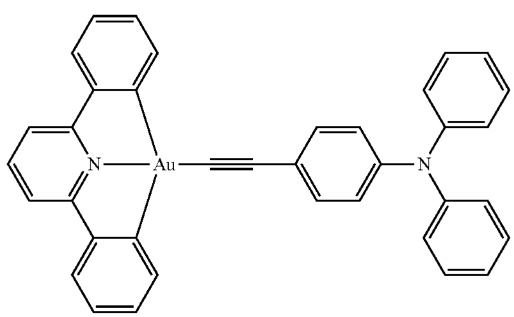
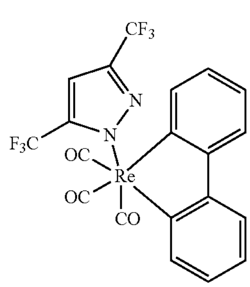
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Cu complexes		WO2009000673
		US20070111026
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium (III) complexes		Inorg. Chem. 42, 1248 (2003)

TABLE 3-continued

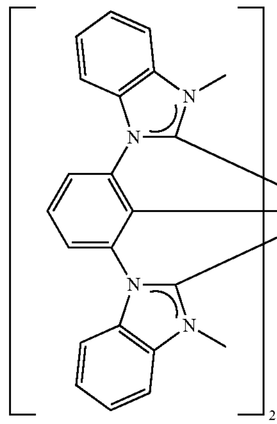
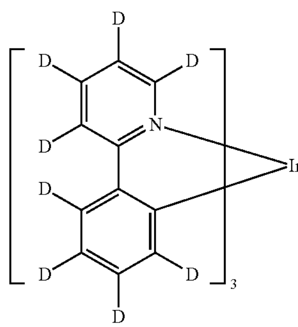
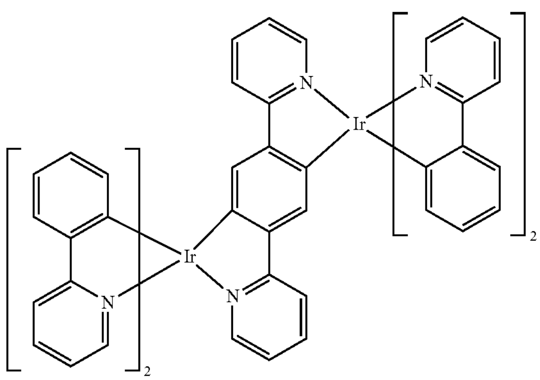
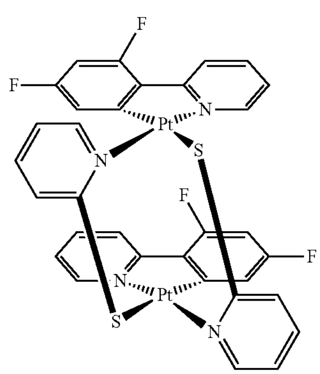
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osmium (II) complexes		U.S. Pat. No. 7,279,704
Deuterated organometallic complexes		US20030138657
Organometallic complexes with two or more metal centers		US20030152802
		U.S. Pat. No. 7,090,928

TABLE 3-continued

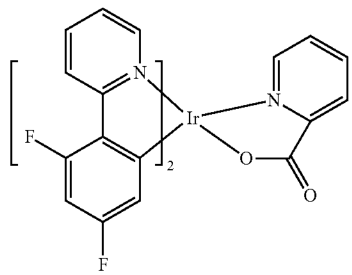
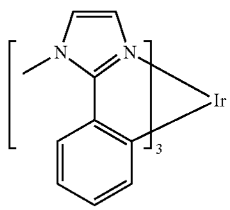
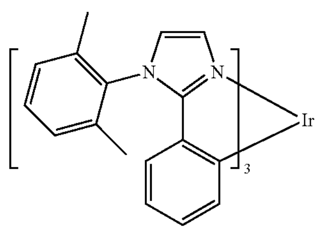
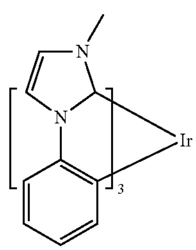
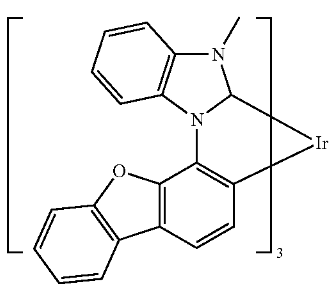
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
	Blue dopants	
Iridium (III) organometallic complexes		WO2002002714
		WO2006009024
		US20060251923 US20110057559 US20110204333
		U.S. Pat. No. 7,393,599, WO2006056418, US20050260441, WO2005019373
		U.S. Pat. No. 7,534,505

TABLE 3-continued

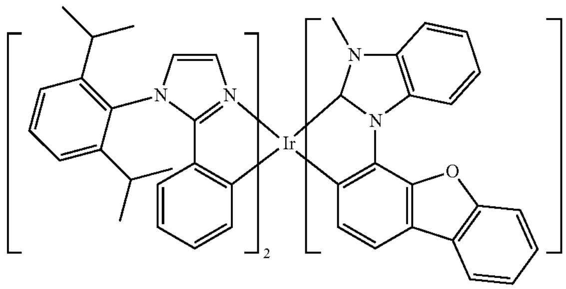
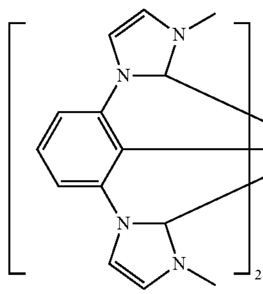
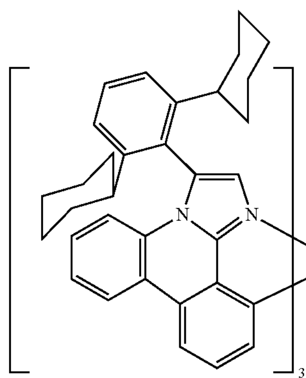
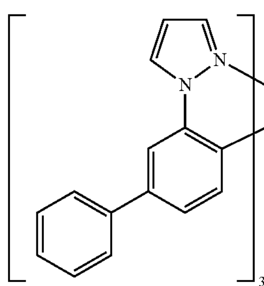
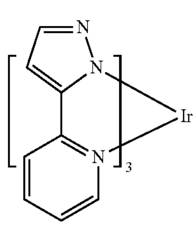
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
		WO2011051404
		U.S. Pat. No. 7,445,855
		US20070190359, US20080297033 US20100148663
		U.S. Pat. No. 7,338,722
		US20020134984

TABLE 3-continued

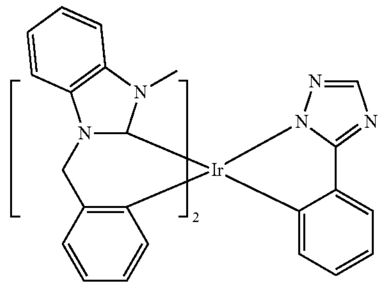
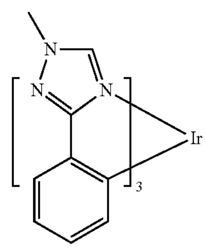
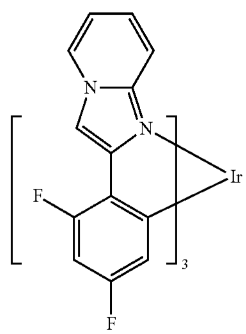
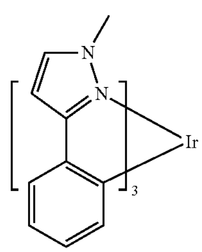
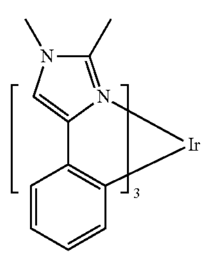
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873

TABLE 3-continued

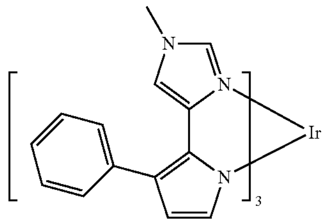
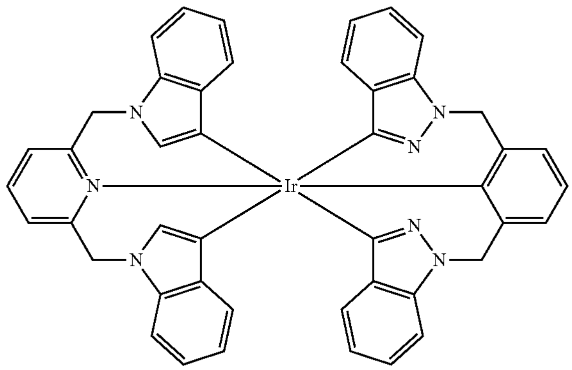
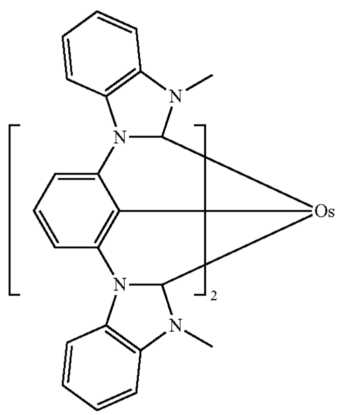
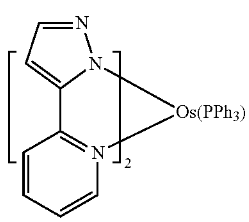
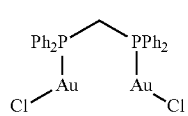
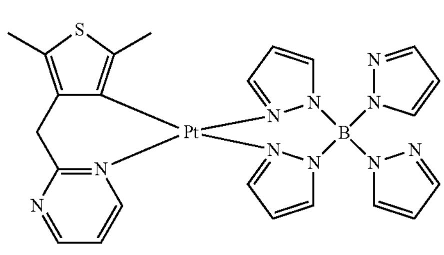
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2007004380
		WO2006082742
Osmium (II) complexes		U.S. Pat. No. 7,279,704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett. 74, 1361 (1999)
Platinum (II) complexes		WO2006098120, WO2006103874

TABLE 3-continued

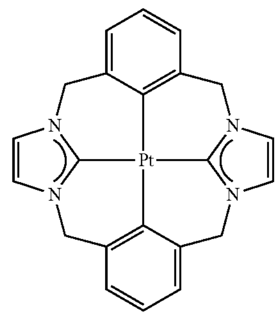
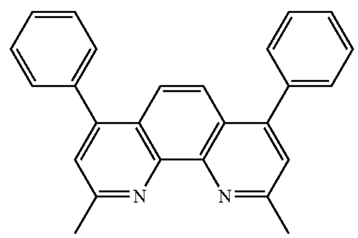
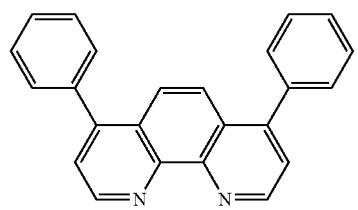
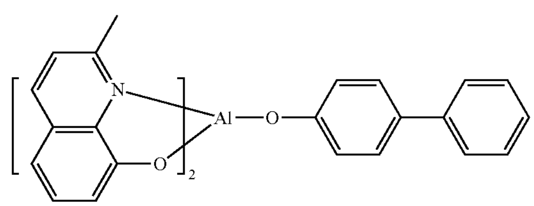
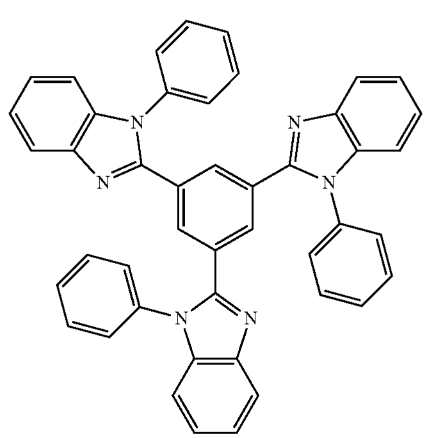
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Pt tetradentate complexes with at least one metal-carbene bond		U.S. Pat. No. 7,655,323
	Exciton/hole blocking layer materials	
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxy-quinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzo-imidazole		Appl. Phys. Lett. 81, 162 (2002)

TABLE 3-continued

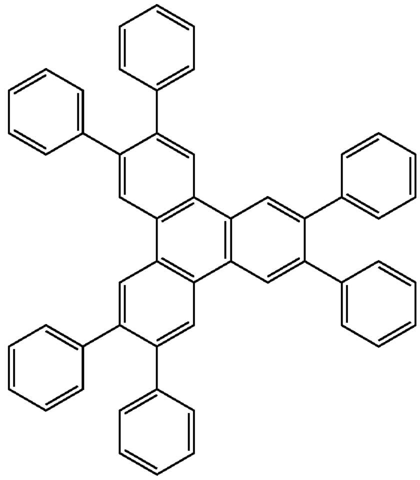
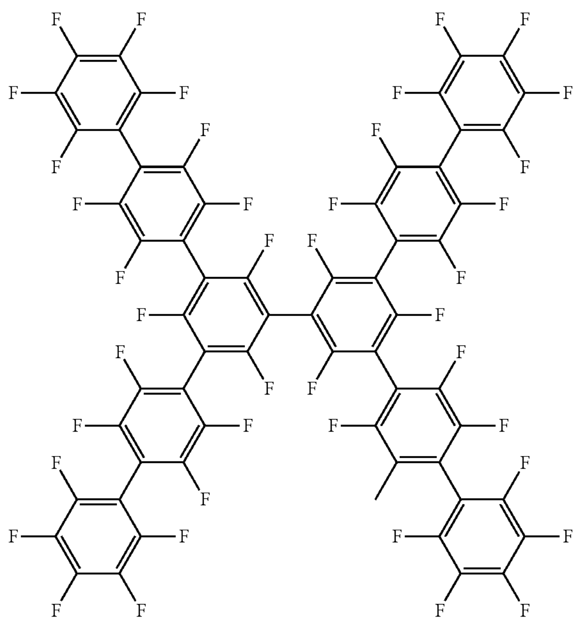
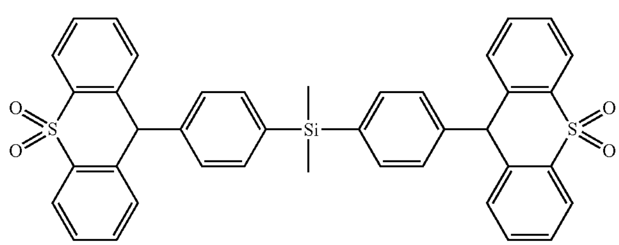
MATERIAL	EXAMPLES OF MATERIAL	PUBLI-CATIONS
Triphenylene compounds		US20050025993
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO2008132085

TABLE 3-continued

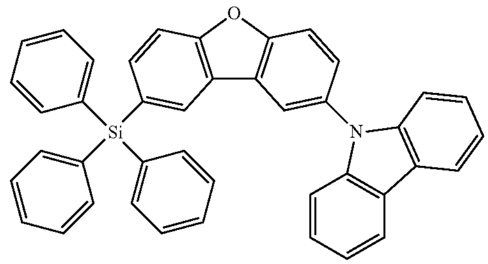
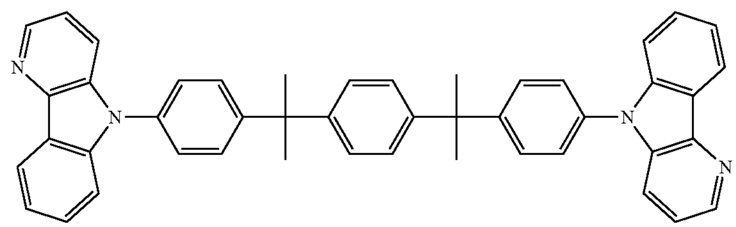
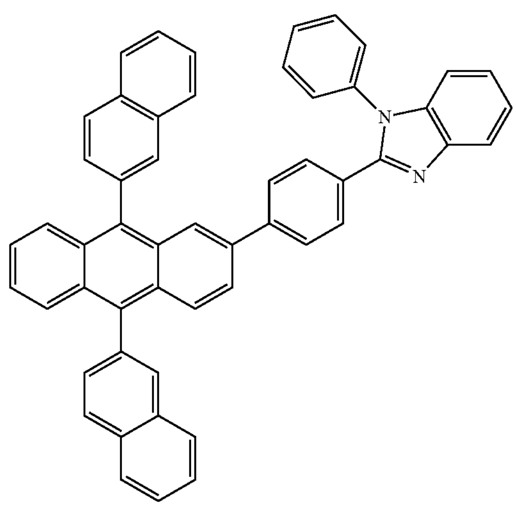
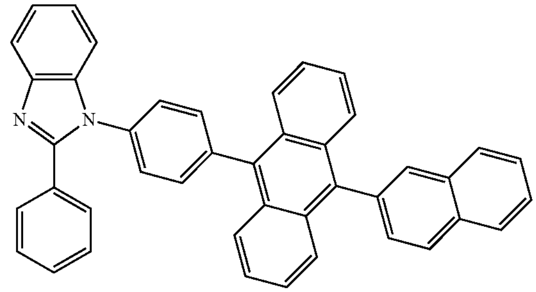
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Silylated five-membered nitrogen, oxygen, sulfur or phosphorus dibenzo-heterocycles		WO2010079051
Aza-carbazoles		US20060121308
	Electron transporting materials	
Anthracene-benzo-imidazole compounds		WO2003060956
		US20090179554

TABLE 3-continued

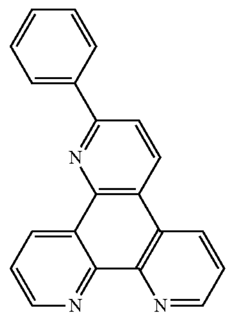
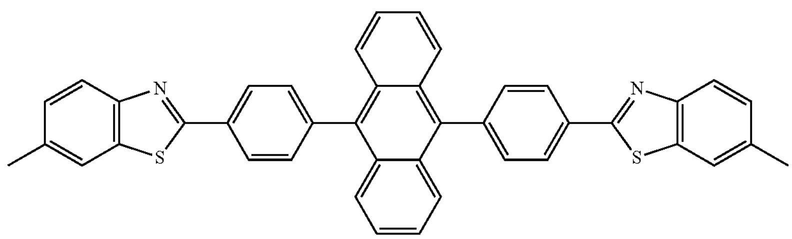
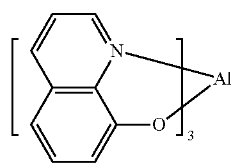
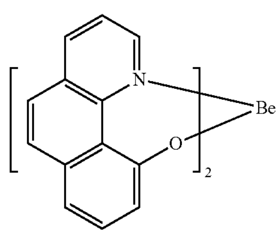
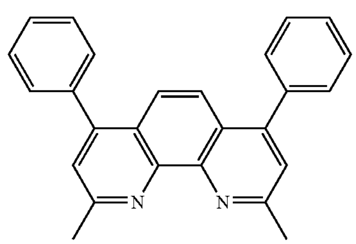
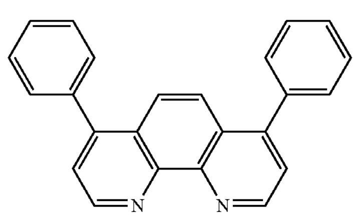
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Aza triphenylene derivatives		US20090115316
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxy-quinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) U.S. Pat. No. 7,230,107
Metal hydroxy-benoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)
		Appl. Phys. Lett. 79, 449 (2001)

TABLE 3-continued

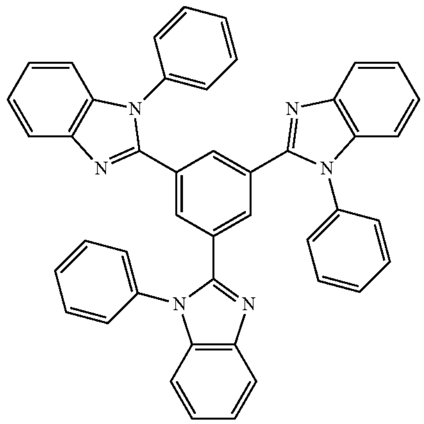
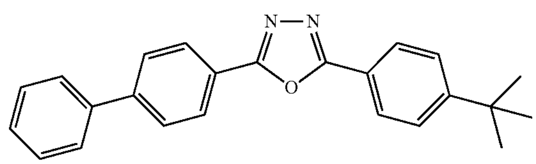
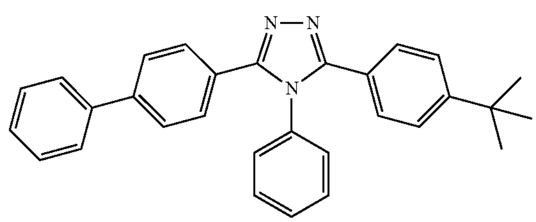
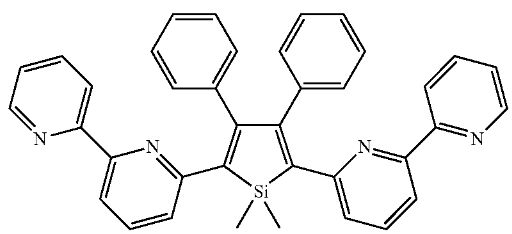
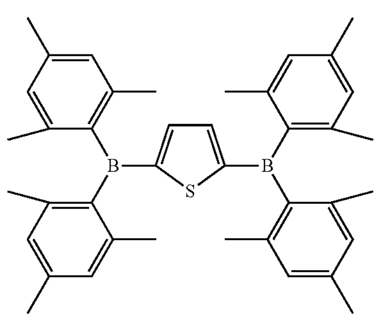
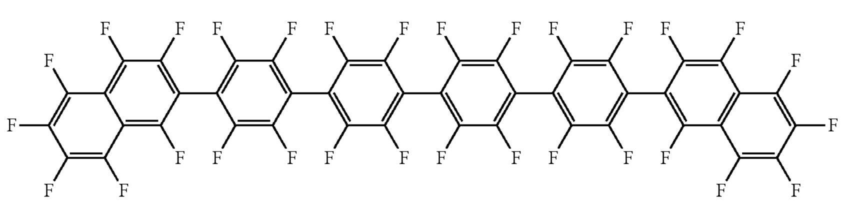
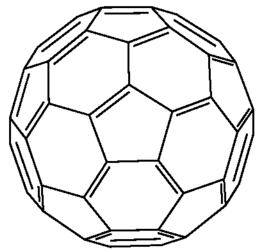
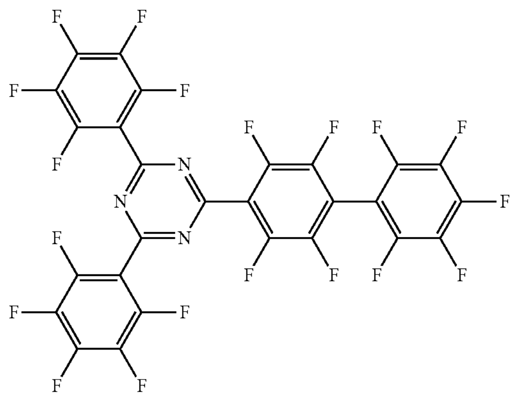
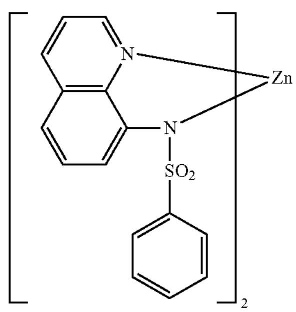
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole, imidazole, benzo-imidazole)		Appl. Phys. Lett. 74, 865 (1999)
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)
Silole compounds		Org. Electron. 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)
Fluorinated aromatic compounds		J. Am. Chem. Soc 122, 1832 (2000)

TABLE 3-continued

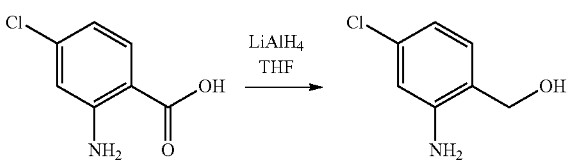
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Fullerene (e.g., C60)		US20090101870
Triazine complexes		US20040036077
Zn (N^N) complexes		U.S. Pat. No. 6,528,187

EXPERIMENTAL

Chemical abbreviations used throughout this document are as follows: Cy is cyclohexyl, dba is dibenzylideneacetone, EtOAc is ethyl acetate, DME is dimethoxyethane, dppe is 1,2-bis(diphenylphosphino)ethane, THF is tetrahydrofuran, DCM is dichloromethane, S-Phos is dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-2-yl)phosphine.

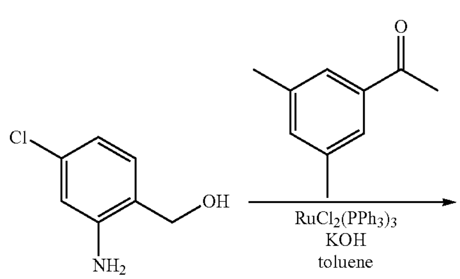
Synthesis of Compound 1

Step 1



2-Amino-4-clorobenzoic acid (42.8 g, 0.25 mol) was dissolved in 200 mL of anhydrous THF and cooled in an ice-water bath. To the solution was added lithium aluminum hydride chips (11.76 g, 0.31 mol). The resulting mixture was stirred at room temperature for 8 hours. Water (12 mL) was added, and then 12 g 15% NaOH, followed by an additional 36 mL of water. The slurry was stirred at room temperature for 30 minutes then filtered. The filtered solid was washed with ethyl acetate. The liquid was combined and the solvent was evaporated to produce crude material, which was used in the next step without purification.

Step 2



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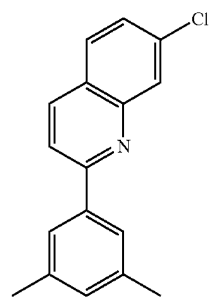
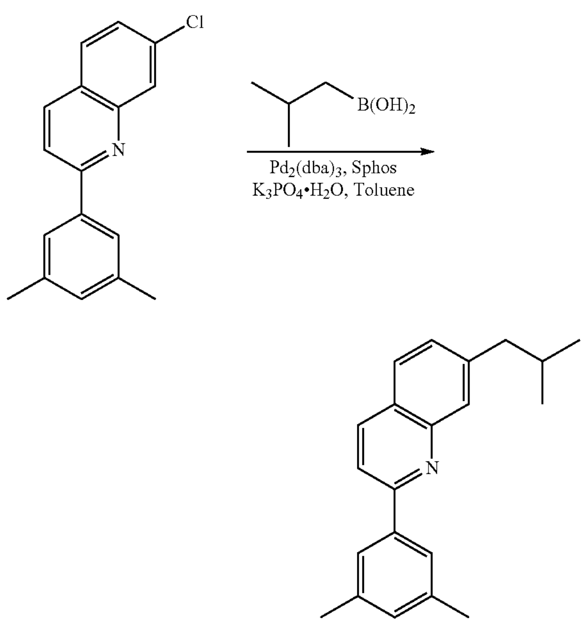


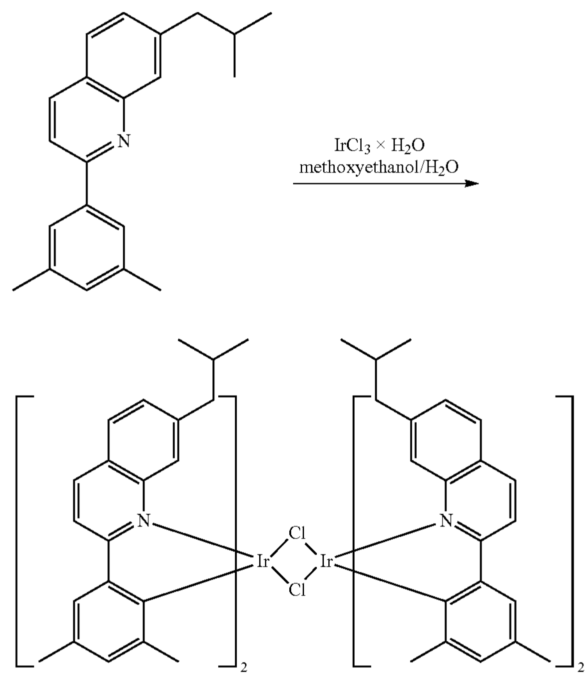
2-Amino-4-chlorophenylmethanol (6.6 g, 0.04 mol), 1-(3,5-dimethylphenyl)ethanone (10.0 g, 0.068 mol), $RuCl_2(PPh_3)_3$ (0.1 g, 12 mmol) and 2.4 g (0.043 mol) of KOH was refluxed in 100 mL of toluene for 10 hours. Water was collected from the reaction using a Dean-Stark trap. After the reaction was cooled to room temperature, the mixture was filtered through a silica gel plug. The product was further purified with column chromatography using 2% ethyl acetate in hexanes as eluent, to obtain 9 g of product. The product after chromatography was further recrystallized from isopropanol to produce 5 g (50%) of the desired product.

Step 3



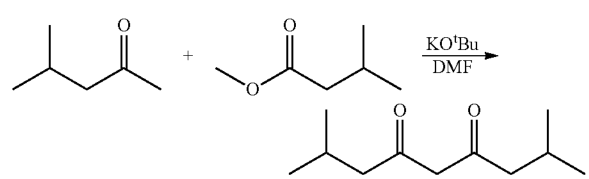
7-Chloro-2-(3,5-dimethylphenyl)quinoline (3.75 g, 0.014 mol), isobutylboronic acid (2.8 g, 0.028 mol), $Pd_2(dba)_3$ (1 mol %), 2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl (5-Phos) (4 mol %), potassium phosphate monohydrate (16.0 g) and 100 mL of toluene was charged in a 250 mL round bottom flask. Nitrogen was bubbled through the reaction mixture for 20 minutes and the mixture was heated to reflux for 18 hours overnight. The reaction mixture was allowed to cool to ambient temperature and the crude product was purified by column chromatography using 2% ethyl acetate in hexanes as solvent to obtain 3.6 g (90%) of desired product after evaporation of solvent.

Step 4



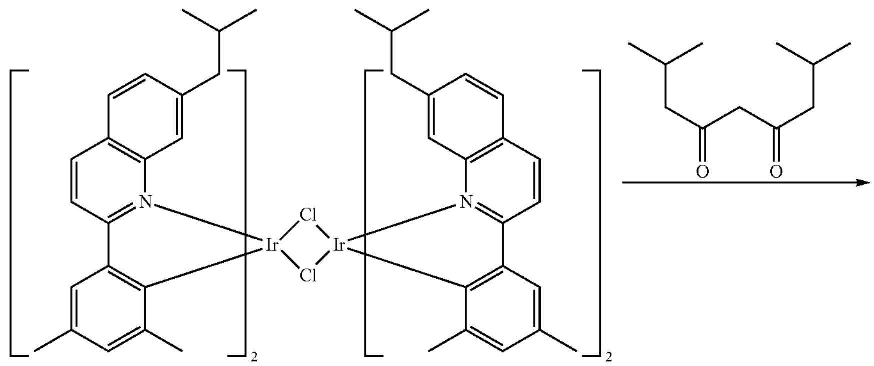
The ligand from step 3 (4.6 g, 16 mmol), 2-ethoxyethanol (25 mL) and water (5 mL) were charged in a IL three-neck round bottom flask. Nitrogen gas was bubbled through the reaction mixture 45 minutes. $IrCl_3.H_2O$ (1.2 g, 3.6 mmol) was then added and the reaction mixture was heated to reflux under nitrogen for 17 hours. The reaction mixture was cooled to room temperature and filtered. The dark red residue was washed with methanol (2×25 mL) followed by hexanes (2×25 mL) to obtain 1.3 g (87%) of the dichlorobridged iridium dimer after drying in a vacuum oven.

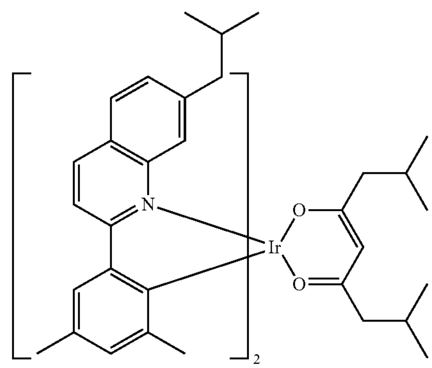
Step 5



N,N dimethylformamide (DMF) (1 L) and potassium tert-butoxide (135.0 g 1.2 mol) were heated to 50° C. under nitrogen. Methyl 3-methylbutanoate (86.0 g, 0.75 mol) was added dropwise from a dropping funnel followed by a solution of 4-methylpentane-2-one (50 g, 1 mol) in 100 mL DMF. The progress of the reaction was monitored by GC. When the reaction was completed, the mixture was cooled to room temperature and slowly neutralized with 20% H_2SO_4 solution. Water (300 mL) was added and two layers formed. The layer containing the 2,8-dimethylnonane-4,6-dione was purified using vacuum distillation to give 40 g (43% yield) of a pink oil.

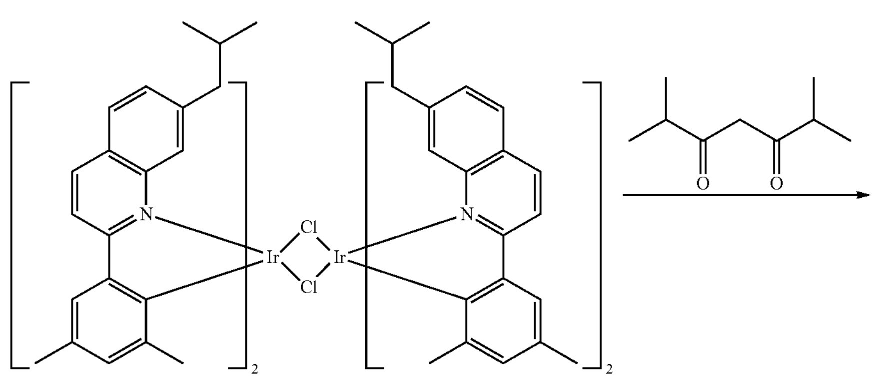
Step 6





The dichlorobridged iridium dimer from step 4 (1.0 g, 0.6 mmol), 2,8-dimethylnonane-4,6-dione (0.8 g, 6 mmol), Na_2CO_3 (3 g, 12 mmol) and 25 mL of 2-ethoxyethanol were placed in a 250 mL round bottom flask. The reaction mixture was stirred at room temperature for 24 hours, after which 2 g of Celite® and 200 mL of dichloromethane was added to the reaction mixture to dissolve the product. The mixture was filtered through a bed of Celite®. The filtrate was passed through a through a silica/alumina plug and washed with dichloromethane. The clarified solution was filtered through GF/F filter paper, and the filtrate was heated to remove most of the dichloromethane. Isopropanol (20 mL) was then added and the slurry was cooled to room temperature and the product was filtered and washed with isopropanol and dried to give 1.1 g (97% yield) of crude product. This product was recrystallized twice from dichloromethane and then sublimed to obtain Compound 1.

Synthesis of Compound 2.



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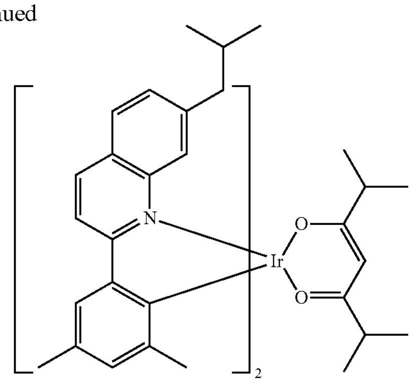


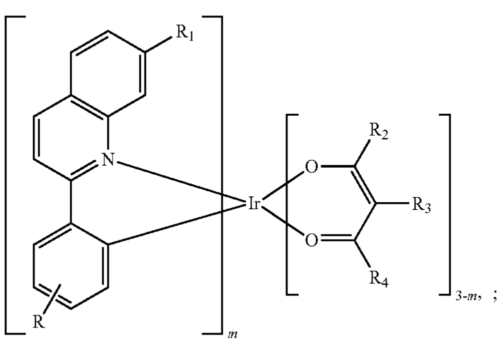
Dichlorobridged iridium dimer from step 4 from the previous synthesis (2.75 g, 1.71 mmol), 2,6-dimethylheptane-3,5-dione (2.67 g, 17.1 mmol), K_2CO_3 (2.3 g, 34.2 mmol) and 25 mL of 2-ethoxyethanol were placed in a 250 mL round bottom flask. The reaction mixture was stirred at ambient for 24 hours, after which. 2 g of Celite® and 200 mL of dichloromethane was added to the reaction mixture to dissolve the product. The mixture was filtered through a bed of Celite®. The filtrate was passed through a through a silica/alumina plug and washed with dichloromethane. The clarified solution was then filtered through GF/F filter paper, and the filtrate was heated to remove most of the dichloromethane. Isopropanol (20 mL) was then added and the slurry was cooled to room temperature and the product was filtered and washed with isopropanol and dried to give 1.49 g (97% yield) of crude product. This product was then recrystallized twice and then sublimed to obtain Compound 2.

It is understood that the various embodiments described herein are by way of example only, and are not intended to limit the scope of the invention. For example, many of the materials and structures described herein may be substituted with other materials and structures without deviating from the spirit of the invention. The present invention as claimed may therefore include variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art. It is understood that various theories as to why the invention works are not intended to be limiting.

The invention claimed is:

1. A compound having the formula:

Formula II



wherein R_1 is cycloalkyl; wherein R_1 has four or more carbon atoms;

wherein R, R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein at least one of the R_2, R_3 and R_4 has two or more carbon atoms;

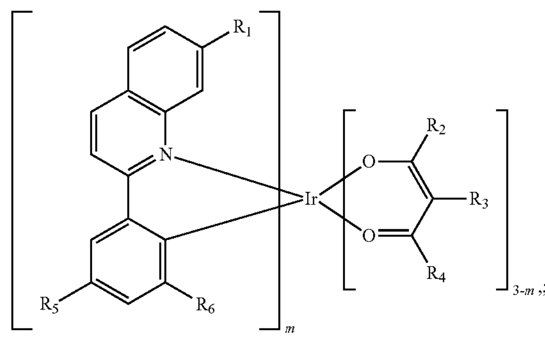
wherein R represent mono, di, tri, tetra substitution, or no substitution;

wherein two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring; and wherein m is 1 or 2.

2. The compound of claim **1**, wherein m is 2.

3. The compound of claim **1**, wherein the compound has the formula:

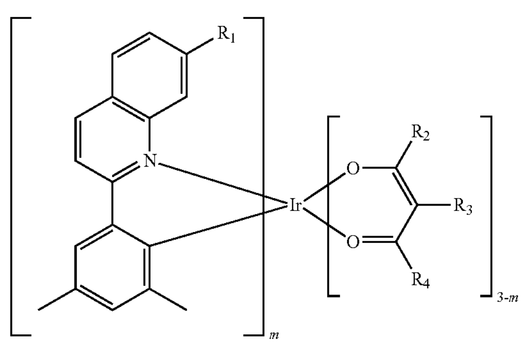
Formula III



wherein R_5 and R_6 are alkyl.

4. The compound of claim **3**, wherein the compound has the formula:

Formula IV



5. The compound of claim **3**, wherein R_1 is selected from the group consisting of: cyclopentyl, and cyclohexyl.

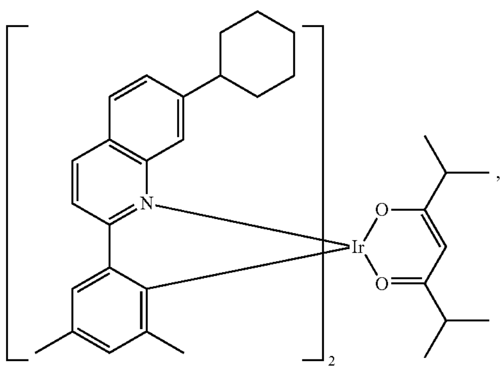
6. The compound of claim **1**, wherein R_2, R_3, and R_4 are independently selected from the group consisting of aryl, alkyl, hydrogen, deuterium, and combinations thereof, and wherein at least one of R_2, R^3, and R_4 has two or more carbon atoms.

7. The compound of claim **1**, wherein R_2, R_3, and R_4 are independently selected from the group consisting of: methyl, $CH(CH_3)_2$, $CH_2CH(CH_3)_2$, phenyl, cyclohexyl, and combinations thereof, and wherein at least one of R_2, R_3, and R_4 has two or more carbon atoms.

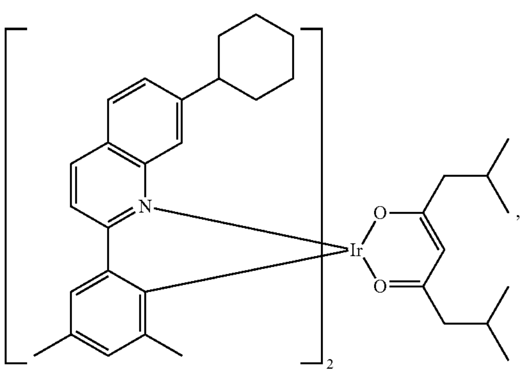
8. The compound of claim **1**, wherein R_3 is hydrogen or deuterium and R_2 and R_4 are independently selected from $CH(CH_3)_2$ and $CH_2CH(CH_3)_2$.

9. The compound of claim **1**, wherein the compound is selected from the group consisting of:

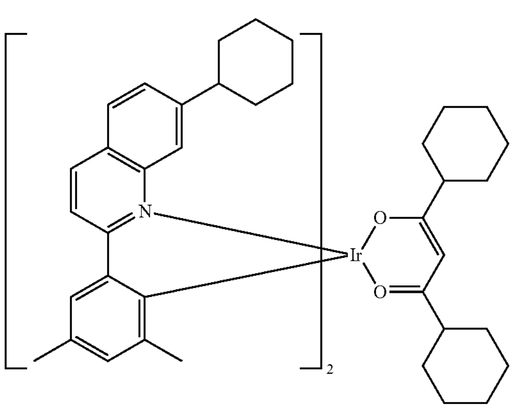
Compound 4



Compound 5



Compound 6



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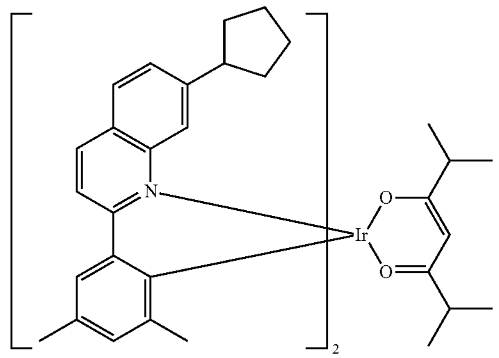
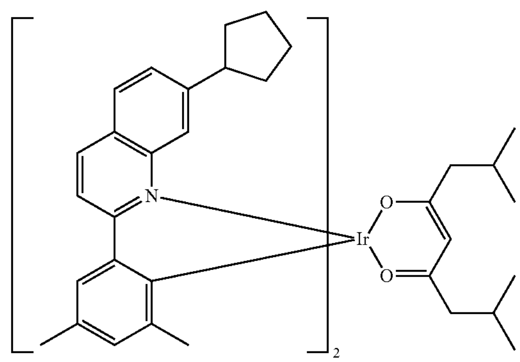
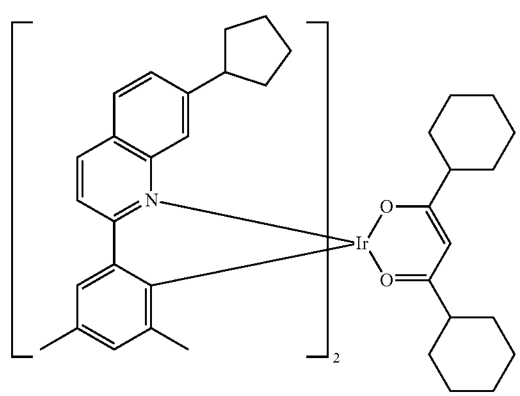
Compound 7



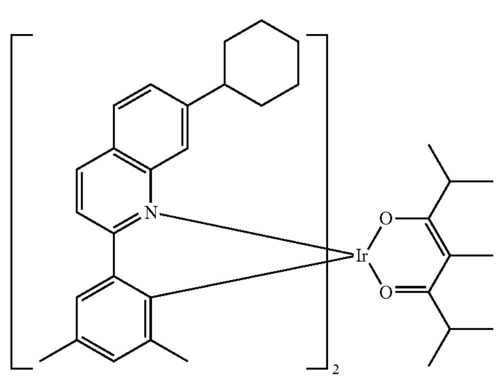
Compound 8



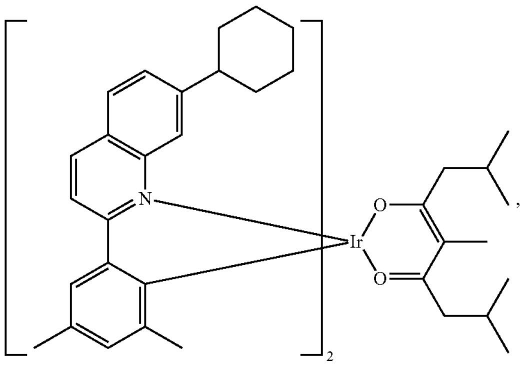
Compound 9



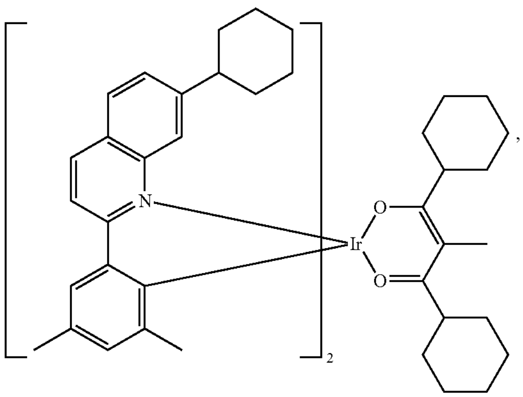
Compound 22



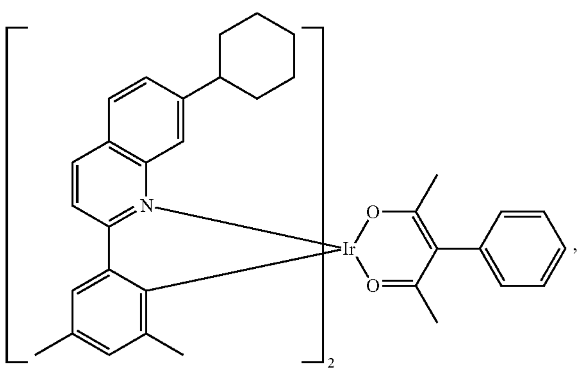
Compound 23



Compound 24

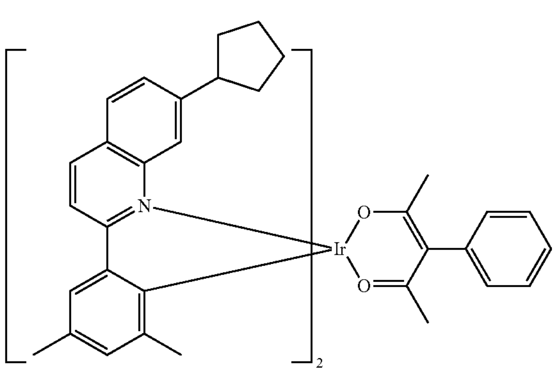


Compound 27

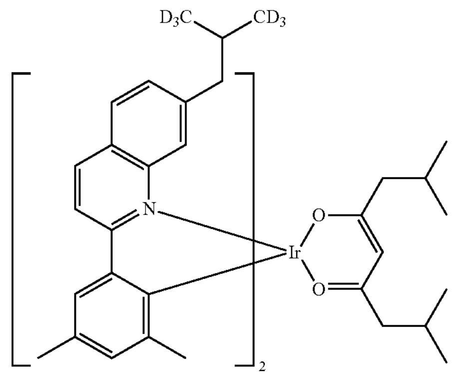


and

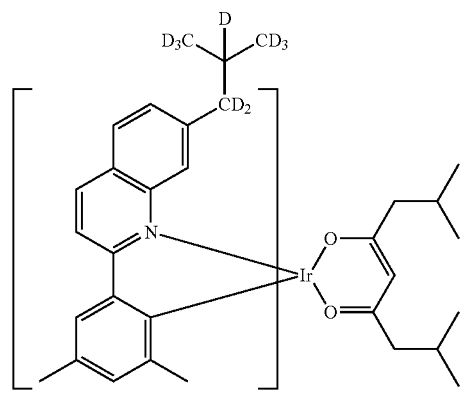
Compound 28



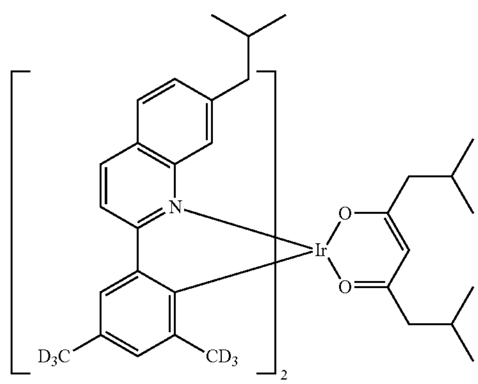
Compound 29



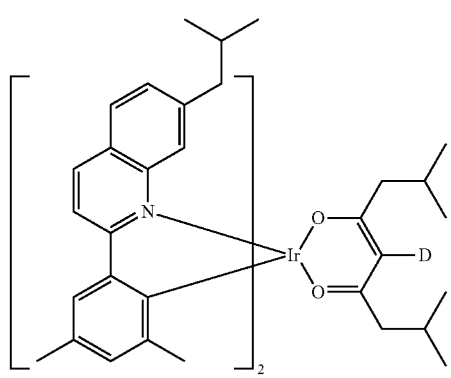
Compound 30



Compound 31



Compound 32



and

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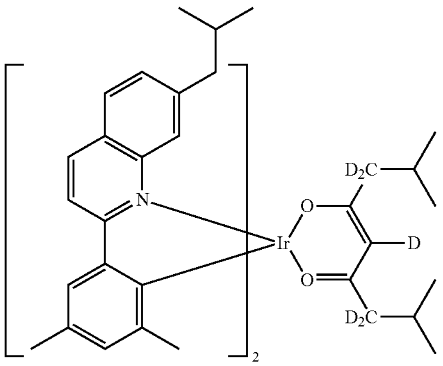
Compound 33



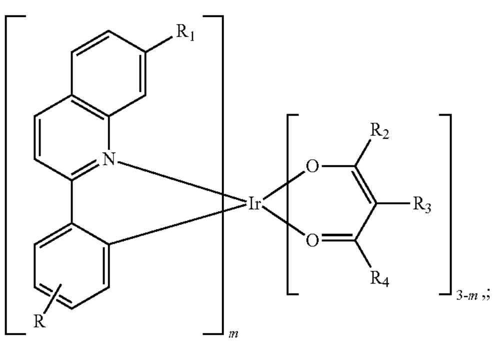
10. A first device comprising a first organic light emitting device, comprising:

an anode;

a cathode; and

an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

Formula II



wherein R_1 is cycloalkyl; wherein R_1 has four or more carbon atoms;

wherein R, R_2, R_3 and R_4 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein at least one of the R_2, R_3 and R_4 has two or more carbon atoms;

wherein R represent mono, di, tri, tetra substitution, or no substitution;

wherein two adjacent R, R_2, R_3, or R_4 are optionally joined to form into a ring; and wherein m is 1 or 2.

11. The first device of claim 10, wherein the first device is a consumer product.

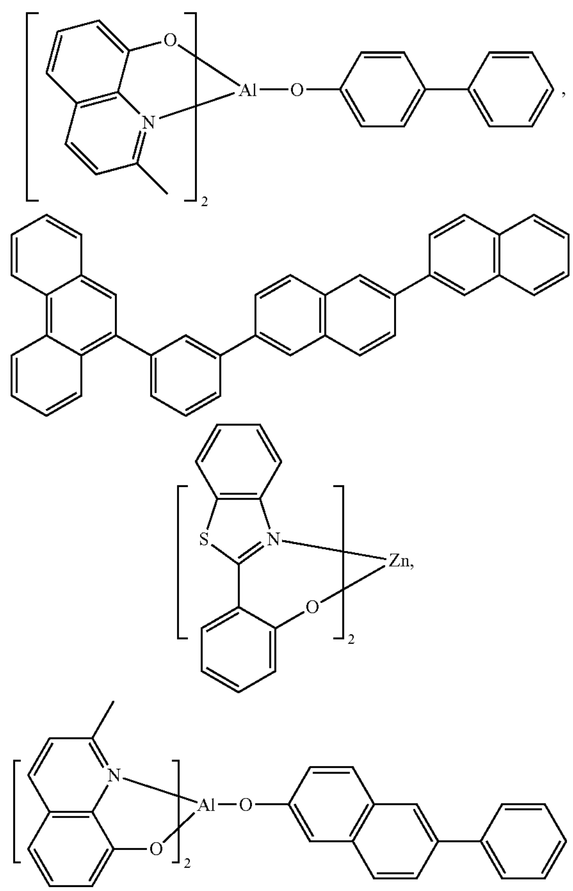
12. The first device of claim 10, wherein the first device is an organic light-emitting device.

13. The first device of claim 10, wherein the first device comprises a lighting panel.

14. The first device of claim 10, wherein the organic layer further comprises a host.

15. The first device of claim 14, wherein the host comprises a metal 8-hydroxyquinolate.

16. The first device of claim 14, wherein the host is selected from the group consisting of:



and combinations thereof.

* * * * *